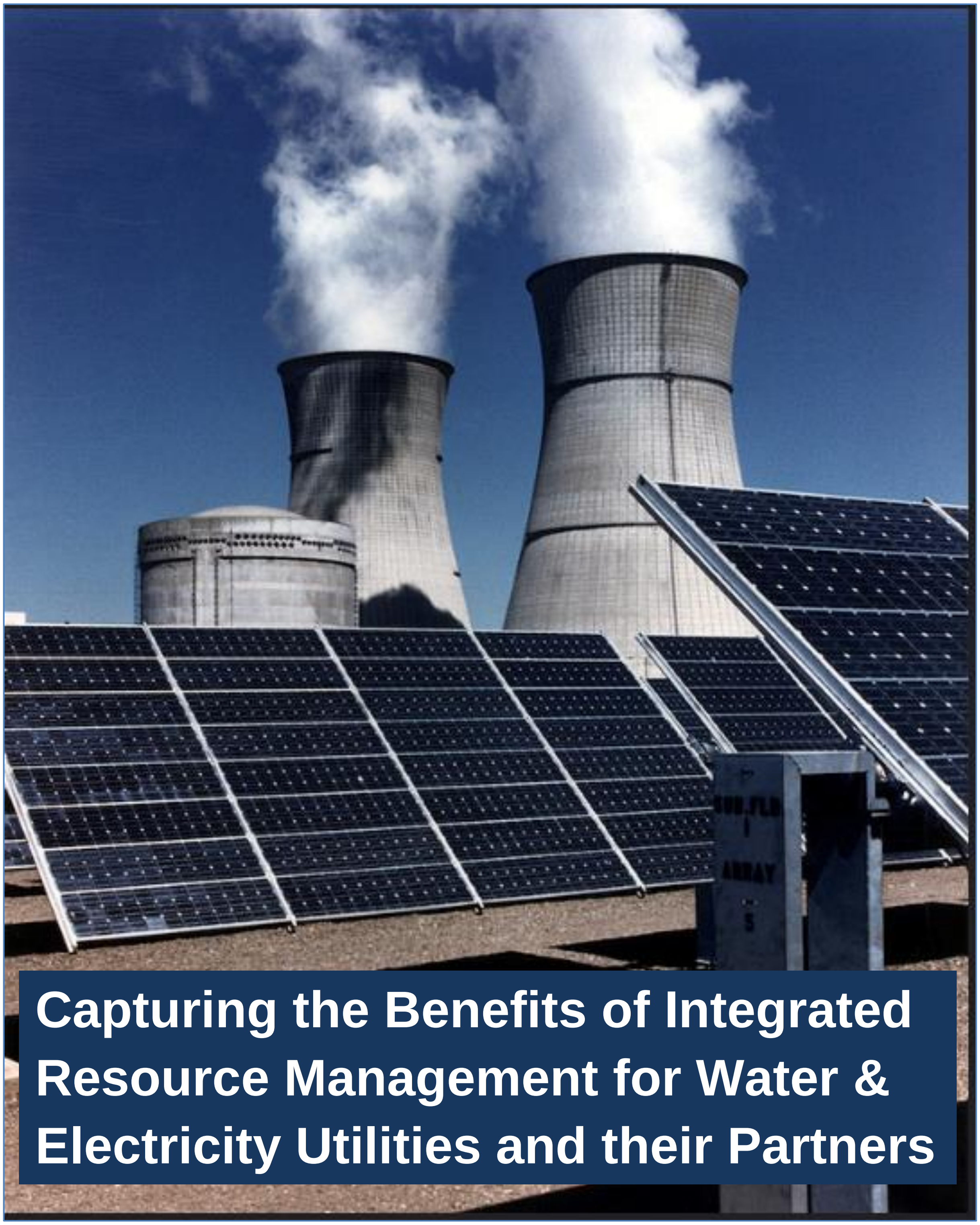

Capturing the Benefits of Integrated Resource Management for Water & Electricity Utilities and their Partners

United States Department of Energy

University of California

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EXECUTIVE SUMMARY

The water and energy sectors have traditionally been studied independently, regulated by separate oversight agencies, and delivered to customers by separate utilities. Yet it is undeniable that there are strong interdependencies between the sectors. Water, in its many forms, has a direct relationship with energy production. Conversely, it takes energy to treat, convey, and purify water.

Mapping out the potential next steps for California and the southwestern U.S. to respond to this dynamic was the primary focus of the joint University of California/Department of Energy Water-Energy Workshop, held on May 28-29, 2015 at the University of California, Irvine. This workshop brought together experts including university researchers, utility providers, state agency representatives from California and the southwestern states, and Federal energy advisors to discuss pressing issues regarding the interactions between water and energy sustainability, with a particular focus on water and electric utilities and related policymaking. This report summarizes discussion at the workshop and provides additional contextual information and discussion.

Reliable and equitable access to energy and water resources is essential for the development and preservation of a resilient and forward-looking society – one that has both a sustainable resource base and a robust economy. In light of continuing changes in physical, economic, and environmental dimensions across the United States, joint solutions for water and energy can help to ensure reliable access to energy and water resources while proactively addressing climate change and grappling with aging infrastructure.

Innovation in the energy and water sectors is required to pursue both climate change mitigation and climate adaptation, as these coupled systems are responsible for a large share of GHG (greenhouse gas) emissions. In the U.S., the electricity sector alone accounts for 31% of total domestic greenhouse gas emissions, including a significant share associated with energy used in the water sector.[1] More understanding of how the combined water-energy system may behave under future conditions or disturbances is needed. For example, climate change impacts on precipitation not only affect water supply security but also hydropower generation, reducing electricity load balancing capability in a time of drought. Additionally, the agricultural sector is associated with high levels of water and coupled energy demands.

In the U.S. water sector, concerns over resilience to drought and water service maintenance have increased as climate patterns have shifted, particularly with ongoing droughts in the southwest. For example, the Colorado River basin has lost roughly 17 trillion gallons of stored water in the past decade due to drought and ever-rising demand.[2] This reservoir decline threatens the long-term water supplies of the seven U.S. states and parts of Mexico the basin includes.[3] In these areas, the

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1 EPA. “Sources of Greenhouse Gas Emissions.” Data from 2013. www3.epa.gov/climatechange/ghgemissions/sources/industry.html

2 S. Castle et al., "Groundwater depletion during drought threatens future water security of the Colorado River Basin", Geophysical Research Letters, doi: 10.1002/2014GL061055 (2014).

3 The data for this study came from the Release 05 of the University of Texas Center for Space Research GRACE data and average water storage changes for the Colorado River Basin were computed as anomalies of terrestrial water storage in equivalent water height.

potential impacts of climate change are projected to reduce the overall precipitation and runoff levels even further. When the rainfall events that do occur are more intense, water management becomes especially important to prevent flooding and loss of potentially useful water.

Considering the interplay between GHG emission reduction goals and resilience to climate change impacts has become more essential. For example, many of the alternative methods for supplementing local water supplies (e.g. desalination, water reclamation, and long distance conveyance) can require significant energy demand. Meeting this energy demand with the current electricity generation fleet will require additional water for cooling and in turn lead to additional GHG emissions.

Over the course of the workshop, participants outlined a strategic vision and accompanying top solutions to address key challenges in the following areas:

- **Emission Reduction**: Reducing greenhouse gas (GHG) emissions of the combined water-energy system.
- **Resilience:** Effectively addressing water and energy system resilience (e.g., handling drought in the water sector, and handling water resource variability and availability in the energy sector).
- **Resource Efficiency:** Increasing the water delivered per unit of energy and energy delivered per unit of water used.

The authors of this report worked to synthesize the discussion at the workshop, as well as to build on the concepts described. This report aims not to be a simple summary, but a comprehensive report which draws on the workshop. Out of the workshop the authors synthesized three key action areas to address the key challenges outlined above:

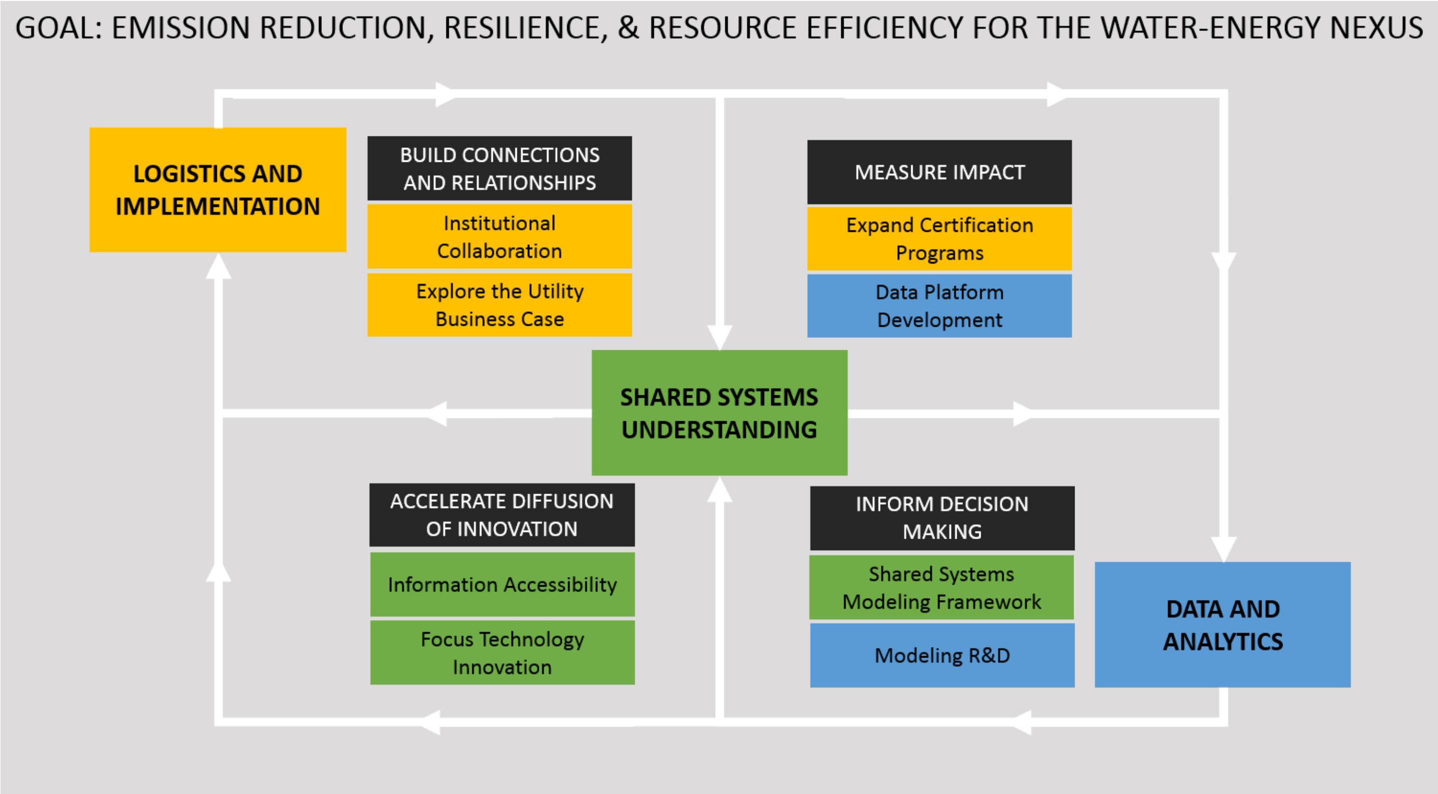
- Shared Systems Understanding;
- Data and Analytics; and
- Logistics and Implementation.

Bridging the action areas to the key challenges are four impact oriented sub-goals that help focus actions and guide development across the framework:

- Build Connections and Relationships;
- Measure Impact;
- Accelerate Diffusion of Innovation; and
- Inform Decision-Making.

For much of this report, examples from California are given, as California has a number of stressors and changes underway that impact the water-energy system. Also, most of the workshop participants in the workshop were from California.

I. Implementation Framework



The above figure outlines the framework developed in this report. Three key action areas, each with associated next steps of the same color, feed into one another in a productive cycle as development progresses, and can result in negative feedback when development stalls. There is no set order to any of the next steps described in this report, but action in all areas is necessary for rapid and coordinated development. The black boxes represent sub-goals of the overall goal of emission reduction, resilience and resource efficiency. The goals are supported through the eight next steps of this report as described below.

SHARED SYSTEMS UNDERSTANDING:

A shared systems understanding takes into account how one activity (policy, operations/management, or technology deployment) impacts the other activity, and vice versa. How the interactions impact the performance of the system needs to be considered in the context of sustainability, and other external goals. Entities that develop targeted actions for meeting water-energy system goals – whether government agencies, universities, or utilities – need a shared systems understanding to effectively coordinate and progress towards meeting their goals.

Addressing the challenges facing the water and energy sectors requires an understanding of how activities impact the combined water-energy system's 1) operations and 2) progress towards meeting holistic goals (GHG emissions, water resource security, and cost of service).

Shared Systems Modeling Framework. A shared systems modeling framework will help to facilitate building institutional knowledge and relationships among water and energy infrastructure, markets, and regulation.

Simultaneously addressing challenges in both the water and energy sectors requires qualitative and quantitative understanding of how activities affect the overall system. A shared systems understanding is needed to accurately simulate the behavior of the combined water-energy system and sensitivities to proposed actions.

A shared systems modeling framework is important for addressing and anticipating future conditions and possible disturbances. For example, climate change impacts on precipitation affect not only water supply security but also hydropower generation. Reduced surface reservoir inflows can compromise bulk hydropower generation and its ability to provide grid reliability and load following services for the electricity system. An integrated modeling framework can provide insight into these impacts and how energy and water planning can address them.

Expanding the scope of analysis of the water-energy system can capture developments in related systems such as food and agriculture. While agriculture was not discussed extensively in the workshop, it was identified as an important area of interest. The agricultural sector has major interdependencies with both the energy and water sectors, and including the agricultural sector in the dialogue of developing a shared system understanding can better inform planning and technological development.

Analytic tools and models that help translate between these systems can improve shared understanding and decision-making. For example, the CPUC water-energy cost effectiveness calculator is a shared systems tool that was designed to help users estimate the saved embedded energy associated with water savings.[4] This helps stakeholders in regulatory agencies and utilities quantify the impact of various efficiency programs.

Information Accessibility. Information sharing at multiple scales across utilities and with customers can improve systems understanding.

The knowledge gained from developing a shared systems understanding is more useful if it is made accessible to relevant parties. Internet-accessible communications that depict the impacts of energy and water efficiency improvements should be widely introduced to utilities and their customers. Precise water-energy reports with mobile access for home use, and accompanying utility side analytics, would provide useful information on energy and water use patterns and interactions.

Utilities can use this information to streamline planning and corrective actions needed for improving system performance (e.g. demand forecasting) and to open up new ways of interacting with

4 California PUC. Water/Energy Nexus, Water Energy Cost Effectiveness Calculator. February 2016 update, with water agency data included http://www.cpuc.ca.gov/nexus_calculator/

customers. Steps for streamlining the process of disseminating water-energy system knowledge to relevant parties are needed, and could be developed by utilities and regulatory agencies.

Focus Technology Innovation. Knowledge gained from shared systems understanding can be used to promote energy and water efficiency innovations by strategically identifying technology development needs, forming a basis for targeted investments in R&D.

Identifying innovative technologies and programs that provide the largest benefit for both sectors can accelerate improvements within the water-energy nexus. Integrated systems models (as mentioned below) can help identify investment opportunities by finding the types of technological innovations and improvements that will have the most beneficial impact on the overall system.

There are many possible targeted R&D investments. For example wastewater reuse, desalination, and irrigation technologies have become much more energy efficient, and targeted R&D investment can yield even greater improvements. Advances in the water-use efficiency of energy related processes such as power plant cooling, manufacturing, or industrial processes also present opportunities. The agricultural sector, which comprises the large majority of total water usage can also be explored and evaluated for contributing towards water-energy system sustainability.

DATA AND ANALYTICS DEVELOPMENT:

The lack of high-quality, granular, easily accessible data on water and energy systems operations prevents effective systems analysis and interagency cooperation. Some of the most significant barriers to interagency cooperation are related to “poor quality or insufficient data to quantify water and energy savings.”[5] Data gaps and data quality issues have limited development of models and analytic tools. Improvements in system operational data collection, quality, and accessibility, as well as advances in analytic methods, can accelerate coordination and improvements in the water-energy space.

Data Platform Development. A data platform is needed for water and energy utilities’ operations that protects personal and proprietary data, aims to improve data accessibility and interoperability, fills data gaps, and informs data quality improvements and standards developments.

Problems with data hinder conservation efforts and much needed analysis, particularly in the water sector. Available data are currently scattered, have limited accessibility, and lack standardization in precision and resolution. To address these issues, a federated approach that links currently available (e.g. California ISO’s OASIS) and emerging databases for common access could be developed. This data platform would improve data accessibility, interoperability, quality and coverage. Over time, this effort can inform the development of data standards.

Water and energy utilities already collect data for their respective domains, and enforced data quality standards could improve the usefulness of these efforts. For example, universities and regulatory

5 Cooley, H. and K. Donnelly, Water-Energy Synergies: Coordinating Efficiency Programs in California. 2013, Pacific Institute. Pg. 7.

agencies could help in developing standards, managing or hosting the federated access point, and developing modes of analyzing and presenting the data.

Modeling R&D. Modeling R&D and development of data analytics will help to leverage the data platform development to better inform decision-making.

Data analytic development can help utilities utilize the data they have to inform decision making. Without proper analytics, some of the benefits of collecting data go unrealized. With improvements in data collection and quality, it becomes possible to develop better models and analytic tools for decision-making within the water-energy nexus. Creating integrated models of water and energy systems requires collaboration between stakeholders in both sectors and can help improve both planning and operation of energy and water systems.

LOGISTICS AND IMPLEMENTATION:

Water and energy utilities operate under different regulatory regimes with diverse public interest and stakeholder engagement concerns. Logistical barriers for collaboration between water and energy utilities exist, despite efforts by both sectors. Energy and water utilities in overlapping territories have not historically had strong working relationships. This can limit the ability to initiate collaboration, as the responsible coordinating parties are not known and a basis for professional trust has not yet been established. While examples of good working relationships exist, the benefits and successes of these relationships are not as visible to the general industry in both water and energy sectors.

Potential opportunities for overcoming existing logistical and financial barriers include the development of frameworks and methodologies for cost allocation, shared system planning tools, a searchable data and information repository, and increasing dialogue with the agricultural water sector. However, these require institutional collaboration, verification and evaluation of conservation programs, and a better understanding of utility business cases.

Institutional Collaboration. Targeted institutional collaboration between water and energy entities (utility-to-utility, agency-to-agency) can bring sustainability benefits.

Successful existing institutional collaborations (i.e. SDG&E and SDCWA) need to be documented and disseminated within the water and energy industries to support development of best practices and a more general understanding of where collaboration can bring benefits.

In parallel, logistical issues that hinder collaboration should be addressed. Some steps include, but are not limited to: 1) Identifying and pursuing small projects that can establish working relationships; and 2) Increasing dialogue with stakeholders (i.e. agricultural water users) in decisions regarding the management of water and energy.

Expand Certification Programs. Conservation certification programs can be expanded to include verification and evaluation after project completion and cross-sector savings.

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.

Separate conservation certification programs exist for certain parts of the water and energy sectors, and the LEED certification has some consideration for water. These certifications can be extended to take into account the projected savings at commissioning and measure/verify actual savings after the fact. As analytic tools improve, it is important to move from certification programs that use a simple "score card" method to one that includes system analysis that address and monitors actual operational performance.

As understanding improves between the energy and water sectors with information sharing and shared institutional knowledge development, opportunities for implementation of programs for water and energy resource management can be further developed.

Explore the Utility Business Case. Developing understanding of utility business cases for water-energy projects can help support conservation efforts. Building understanding of the short and the long term benefits to the water and energy sectors of investment decisions can help to inform sector investments and also identify potential gaps in investment which Government programs could address.

The impact of rate making differences across the sectors is important to consider when prioritizing internal investment. With the understanding of where utilities are likely to be investing on their own (in both the long term and short term), government can prioritize its own investment in areas such as data, modeling, and R&D.

II. Conclusion

The UC/DOE Water-Energy Workshop brought together experts from academia, industry, national laboratories, and regulatory agencies representing California and the southwestern states to discuss pressing issues and potential solutions with water and energy sustainability. A number of productive discussions occurred, and based on the workshop content and additional reflection on the discussion, three focus areas were distilled: 1) shared systems understanding, 2) data and analytics, and 3) logistics and implementation. The associated next steps are offered as ways to address the key challenges of the water-energy system.

The full report highlights and describes key obstacles for simultaneously addressing energy and water-related challenges. The first chapter provides a description of the context and background information. The next three chapters describe each of the action areas for water and energy entities as interpreted from the workshop discussions. Finally, chapter 5 summarizes the focus areas and next steps and identifies additional areas of investigation.

III. Acknowledgements

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Photo credit: DOE

Contents

Chapter 1 – Background

In order to understand water-energy system, it is important to capture: 1) the differences in each system's operation and management principles and 2) how the two systems interact. This section is aimed at providing a brief description of key aspects of how the energy and water systems are operated and managed while highlighting examples of their interdependency to contextualize the needs and potential solutions outlined in the remainder of the report.

1.1. System Operation, Management, and Key Differences

Energy and water systems have different paradigms that govern how they have been operated and managed. These differences include, but are not limited to, different degrees of control over resource supply, different timescale of supply and demand balancing, different definitions for reliability and resiliency, and varying spatial organization across their service areas.

1.1.1. Control of Resource Supply

The energy and water systems have different degrees of control over the primary supply of energy and water resources.

The energy system has historically been designed to allow system operators to have a high degree of control over the production of energy in various forms (electrical, thermal, mechanical, etc.). Primary energy resources have typically been comprised of solid or liquid fuels that can be stored and used when needed (i.e. coal, uranium, and petroleum – and even hydropower). For example, power plant operators have control over when input fuel coal or oil is burned in their units to produce electric power. These resources are dispatchable, which allows system operators to time the generation of electricity to meet demands. Resources that are not dispatchable (such as wind, solar, and tidal power) have out puts that are subject to environmental factors, and require extensive forecasting to determine their availability for power generation. System operators must coordinate their dispatchable generation (and dispatchable load in the form of demand response) with the non-dispatchable generation (and non-dispatchable demand) to ensure that loads are satisfied reliably.

In contrast, the water system does not have a high degree of controllability. Whether as rain or snow, water supply manifests as runoff to be stored in both natural and man-made surface water reservoirs, or as infiltration to be stored in groundwater reservoirs. Precipitation patterns are governed by weather and climate factors for any given region. Storing precipitation in large reservoirs allows some controllability to ensure that the demand is met. Demand for water tends to be controlled and adjusted instead of supply. This practice has limits when major drought events from the lack of precipitation causes reservoir levels to decline. Concerns over escalating drought events have brought increased attention to alternative saline water supplies that can be – through desalination -- dispatched to provide a water supply during droughts. These resources are already in use in historically arid areas of the world. Saline resources have been used at a small scale in California, but the recently completed Carlsbad Desalination Project suggests a rising importance. Small-scale desalination plants in California are comprised of facilities which are used for cleaning brackish groundwater inland or as emergency supply for island towns such as Avalon on Catalina Island.

Large-scale desalination plants are coastal facilities used for supplementing the primary water supplies of cities or other densely populated areas. Large scale facilities are in operation in areas of the world such as the Middle East.

The difference in the control of resource supplies for the electricity and water sectors presents an opportunity for each sector to learn from the other's operational and design experience. For example, the electricity sector can incorporate the modulation of demand and use of storage in response to variable supply from renewable resources, similar to the way the water sector utilizes variable supply from precipitation. Conversely, the water sector can utilize dispatchable supply through implementation of desalination and water resource recovery to better control the water supply base and build resilience. Incorporating the lessons learned can help both sectors to be more adaptable in the face of shifting climate patterns.

1.1.2. Timescale of Supply and Demand Balancing

Another key difference between the water and energy systems is the timescale for matching supply with demand.

In the electricity sector, supply and demand must be matched over periods of seconds to minutes for the system to function. Changes in demand require immediate changes in supply, accomplished by the start-up/shut-down or ramp up / ramp down of dispatchable power plants. Mismatches in the supply and demand for electricity have consequences for many electricity system operating parameters, such as the electric grid frequency and transmission / distribution line voltages. When these parameters fall outside of design specifications, equipment damage or malfunction and transmission failures can result.

In contrast, the demand and supply for water does not have to match over short timescales, and resource balancing is typically planned over long time horizons. Precipitation cycles occur on the timescale of years and with seasonal variation. The presence of significant storage systems allows the buffering of short-term imbalances to a certain extent, and short-term changes in supply or demand are not considered as a priority for the system.

1.1.3. Concepts of Resiliency

A third difference between the water and energy systems is the nature of how they view resiliency. Both systems must be prepared for events that damage their physical infrastructure, such as wildfires, which can damage natural gas pipelines and electricity transmission lines; or earthquakes, which can cause breaks in water mains. Beyond repairing damaged infrastructure, the differences in the timescale of supply and demand balancing have implications for the other types of events that each system is primarily concerned with being prepared for.

In the electricity system, the short-timescale nature of supply and demand balancing leaves the system vulnerable to short-term disruptions. An unexpected loss of generation or transmission capability has an immediate and spatially widespread impact on consumers, and the response of the system to these contingencies occurs in a matter of seconds to minutes. Reserve generation capacity that can provide power in seconds to minutes to keep the load balanced in the overall system or in a particular region can increase system resilience by reducing the impact of these events. This reserve generation can be sourced from power plants that are already online and have extra capacity, and by inactive power plants that can be started-up and provide power in a short amount of time. These measures are made possible by the high level of control over fuel supply that electricity system managers have in the electricity system. Long-term variation in demand is considered a planning issue rather than a resiliency issue.

In the water system, resiliency is generally focused more on much longer timescale, due to the long-term nature of supply and demand balancing for water. The presence of storage renders the water system relatively unaffected by short-term disturbances, such as storms, seasonal dry periods, or temporary increases in water demand. Such events do not typically interrupt water service to consumers on a large scale. At local scales, however, it is important to note short-term disturbance events caused by infrastructure component failure (e.g. pipe rupture) can immediately affect local customers. In standard operation, the inability to control long term water supplies is the primary resiliency concern in the water system. Measures to respond to drought are diverse, including building storage capacity, water efficiency, and utilizing alternative water supplies.

1.2. Technical and Economic Couplings between Water and Energy Sectors

Historically, the water resource and energy supply systems have been designed and operated separately from one another. Power plant operators know that their units will need water for cooling, however potential impact on water resource security or water system operations is not commonly considered or understood. Similarly, the operator of a wastewater treatment plant knows that their units will require electricity, but the impact of those loads on electricity system operations is not commonly understood, and so potential opportunities in energy from wastewater bio-solids are often left unexplored.

1.2.1. Energy Usage in Water Resources

Non-trivial energy inputs are required for the water sector to operate. Many technologies that may need to be deployed to secure water resource resiliency also require significant energy inputs. Energy is also used for water-related end uses after it is delivered to consumers.

1.2.1.1. Energy Intensity of the Water Supply Infrastructure

The Southwestern United States relies on the transfer of water across long distances and the import of water into geographically divided regions. This is especially true for California. The water supply infrastructure can be viewed as having four distinct components. Each requires energy inputs, and some have potential outputs:

- **Conveyance:** The long-distance transport of water from areas with historically high precipitation and runoff to areas where it is used for urban or agricultural purposes.
- **Treatment:** The removal of compounds, micro-organisms, and other undesirable characteristics from a volume of water extracted from natural reservoirs (surface or subsurface)
- **Distribution:** The delivery of water to end-users over shorter distances, after treatment.

- **Wastewater Treatment:** The treatment and clean-up of water (primarily municipal wastewater) that has been utilized for various purposes to standards suitable for discharge into water bodies without degrading water quality – or for re-use for various potable and non-potable purposes.

Collectively, conveyance, treatment, distribution and wastewater treatment accounted for about 6% of the total electric energy demand in California.[6] This may be slightly higher than that for other regions, due to the high conveyance energy requirements in the state. However, this is a non-trivial percentage of the total energy demand.

Conveyance requires large energy inputs in the form of electricity and natural gas for operating the large pumping stations required to produce enough pressure to move water over large distances and varied terrain. The energy required for conveyance varies depending on the type of territory that needs to be traversed. On the low end, conveyance may require little to no energy at all with gravitational flow or energy recovery devices in conveyance pathways. On the high end, energy needs can be large due the pumping of water over mountainous regions. In California, water conveyance is estimated to be an average of 8900 kWh/MG and is a relatively steady load.[7]

Many treatment methods are chemically-based and do not use direct energy inputs, although electricity is still required for the general operation of the facilities. The energy used is mostly associated with moving water through the different stages of the treatment plant. In California, treatment is estimated to be an average of 10-78 kWh/MG for historical processes.[8] Increased water quality standards and the desire to clean up and use impaired water bodies may require the use of more energy-intensive processes like UV radiation treatment.

Distribution of water requires energy primarily for pumping water to overcome gravity and viscous losses in water pipes to maintain the desired pressure at the location of the end users. The energy inputs for distribution can also vary depending on the local territory. In California, average energy intensity of water distribution is about 1250 kWh/MG.[9]

Wastewater treatment requires energy inputs for pumping water within facilities, and for various treatment processes. The level of energy required depends on the desired degree of treatment. Since wastewater flows have higher concentrations of organic solids, more energy is required to pump wastewater than pure water. In California, average energy intensity of wastewater treatment is about 2500 kWh/MG.[10] It is important to note that wastewater treatment facilities have the potential to provide energy outputs as well. Energy from bio-solids in municipal waste, in the form of biogas, can be harvested with the proper equipment and can partially or wholly meet the energy needs of the

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6 California's Water-Energy Relationship, 2005, California Energy Commission.

7 California's Water-Energy Relationship, 2005, California Energy Commission.

8 California's Water-Energy Relationship, 2005, California Energy Commission.

9 California's Water-Energy Relationship, 2005, California Energy Commission.

10 California's Water-Energy Relationship, 2005, California Energy Commission.

wastewater treatment processes, or even allow for the production of energy above these needs depending on facility size and configuration.

1.2.1.2. Energy Intensity of Alternative Water Supply Measures

Many of the technologies that may need to be deployed to secure water resource resiliency require significant energy inputs. For building long term resiliency into the available water supply two primary technologies stand out: desalination and water reuse.

Desalination refers to the removal of salts and other dissolved solids from water sourced from oceans, saline aquifers, or subsurface energy reservoirs. This can be accomplished with membrane or thermal processes, both of which require significant energy inputs. Seawater reverse osmosis desalination requires significant electric energy inputs on the order of 11634 – 17803 kWh/MG (3.0 - 4.7 kWh/m^3) to generate the pressure needed for the separation of solids.[11] Brackish water desalination, which uses impaired groundwater, has generally lower requirements due to lower dissolved solid concentrations. Thermal processes require significant heat input to drive the distillation process in addition to electric energy inputs to pump water around the plant. Systems such as multi-effect evaporation require electric energy inputs of about half of what is required for membrane desalination, but this is still a thermal energy input an order of magnitude higher than its electric energy inputs. There are systems that utilize waste heat from power generation for the desalination process,[12] but the potential and feasibility of such systems is dependent on the quantity and quality of waste heat.

Water reuse refers to the additional treatment of a wastewater treatment plant's effluent to standards that are acceptable for discharge into natural or man-made reservoirs for primary water supplies or other uses. For drinking water, these standards are higher than those required for discharge into the environment (i.e. into rivers or the ocean). Treatment processes include microfiltration, reverse osmosis, and advanced oxidation processes which require electric energy inputs. The energy intensity of these processes vary depending on the characteristics of the input stream.

Other measures are available for aiding in water resource availability. Groundwater banking enables distributed subsurface storage of water during years when there is abundant rainfall, which can later be pumped and used during years when water is harder to come by. Water conservation and storm water capture strategies have significantly lower or resulted in zero direct energy requirements, but may be limited in capacity or may not entirely decouple water resource availability from climate patterns.

11 Ettouney, H., Visual Basic Computer Package for Thermal and Membrane Desalination Processes. Desalination, 2004. 165: p. 393-408.; Al-Karaghouli, A. and L.L. Kazmerski, Energy consumption and water production cost of conventional and renewable-energy-powered desalination processes. Renewable and Sustainable Energy Reviews, 2013. 24(0): p. 343-356.

12 World's first desalination unit utilizing waste heat on Maldives. 2014; Available from: http://www.memsys.eu/projects-details/worlds-first-desalination-unit-utilizing-waste-heat-on-maldives.html.

1.2.1.3. Energy Intensity of Water-Related End Uses

In addition to both operational and alternative supply aspects, energy is used for water-related end use after it is delivered to consumers. Examples of include pumping for irrigation in agriculture, the operation of certain appliances (such as dishwashers), and the heating of water for various residential, industrial, and commercial sectors. The forms of energy used for water-related end use include both electricity and fuel usage.

In California, the energy use due to water related end uses comprises the majority of the overall water-related energy use.[13] In 2001, end-use comprised 73.4% of the total water-related electricity use and 98% of the total water-related natural gas use in the state. As the implementation of water and energy efficient appliances grows, there is significant opportunity to reduce energy consumption due to water-related end use.

1.2.2. Water Usage in the Electricity Infrastructure

Water inputs are required for the operation of the energy infrastructure. Below are just a few examples of the known interdependencies, but an understanding of these can help identify potential opportunities in meeting GHG reduction and water resource resiliency goals. These interactions should to be taken into account for planning purposes to support a resilient water resource supply that can help the energy sector to reduce greenhouse gas emissions.

1.2.2.1. Power Generation

The vast majority of electric power generation in the U.S. is from thermal power plants that can require water for cooling processes. Generators convert thermal energy to mechanical energy and on to electric energy. Gas-turbine power plants (which have relatively low water requirements) and steam-turbine power cycles are combined to make combined cycle gas turbines (CCGT) which increases generation efficiency. The thermal energy can be sourced from coal, natural gas, nuclear, or renewable resources (i.e. solar radiation, geothermal, or bio-derived fuels). CCGT and steam turbine power plants require water to provide cooling for the steam turbine condenser and allow the plant to continually operate, however the water requirements can vary depending on the type of cooling system and the type of generation cycle.

Power plants that utilize once-through cooling systems subsequently return the heated water to the immediate environment. These systems have high water withdrawals but relatively low water consumption. While these systems do not reduce the amount of water available in a given reservoir, they require water reservoir volumes be maintained to support the large withdrawal rates. Power plants that use evaporative cooling towers intake water and use the latent heat capacity of the water to provide cooling, causing the water to evaporate into the atmosphere. These systems have relatively low withdrawals, but have high water consumption rates that must be compensated to maintain reservoir levels.

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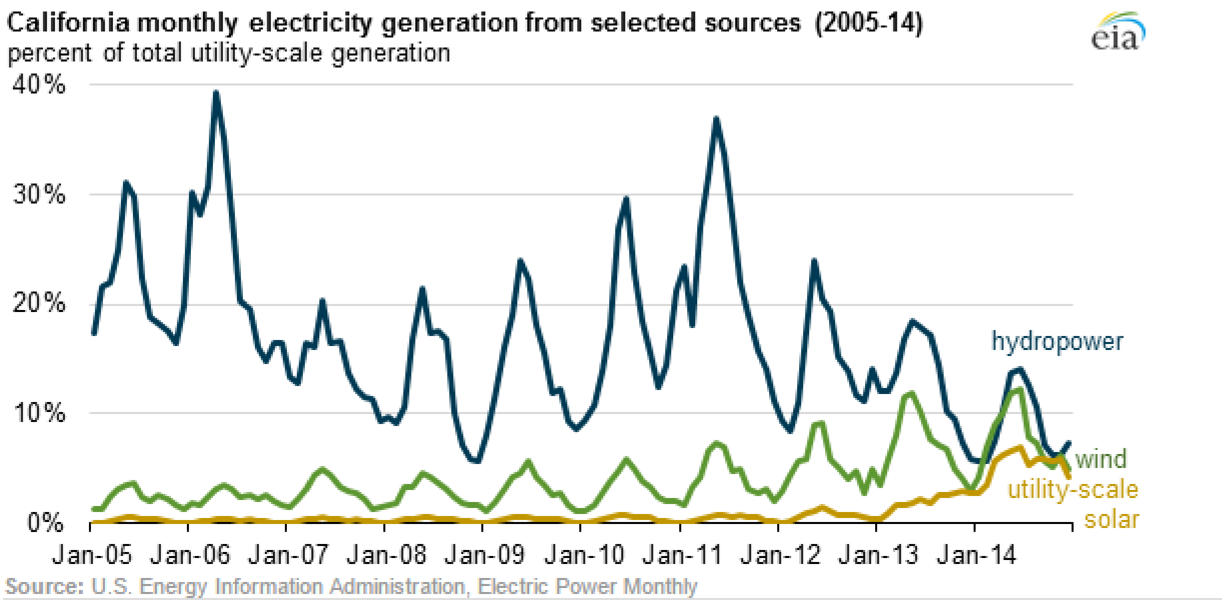
13 California's Water-Energy Relationship, 2005, California Energy Commission

Water use in thermal power plants is affected by the efficiency of the power plant. Less efficient, typically older thermal power plants produce more heat per unit of fuel input, and therefore require more water for heat removal compared to newer, more efficient thermal power plants.

Certain types of renewable resources can have high water consumption rates. For example, solar thermal and geothermal electricity generation may reduce electricity-related greenhouse gas emissions, but the generation technology can have high water consumption rates. In an area with high solar thermal or geothermal resource potential, the lack of water resource availability can be a constraint that requires the re-development of energy resource procurement plans.

1.2.2.3. Role of Hydropower in Grid Management

Water resources fulfill a major role in the management of the electric grid through hydropower dispatch. Hydropower does not produce GHG emissions in operation, provides a high amount of dispatch flexibility on short timescales, and can provide ancillary service support (i.e. reserve capacity and regulatory support).



In California hydropower has provided roughly 10% of the annual electricity supply, 80% of the contingency reserve service capacity, and 30-45% of the regulation capacity in non-drought years.[14] Under the drought year of 2014, the contribution of hydropower to electricity generation has been dramatically reduced compared to the wet year of 2011.[15]

The water into hydropower reservoirs from precipitation and runoff are dependent on climate patterns. The projected impacts of climate change can reduce overall precipitation in the southwestern U.S and decrease hydropower reservoir levels. This has implications for the role of hydropower in providing minute, hourly, and diurnal demand management as a dispatchable generation resource. With

14 Western Markets Investigation Data, 2002, Federal Energy Regulatory Commission.

15 California Drought Leads to Less Hydropower, Increased Natural Gas Generation. 2014; Available from: http://theenergycollective.com/todayinenergy/2116946/california-drought-leads-less-hydropower-increased-natural-gas-generation.

reduced reservoir levels, hydropower units may not have the flexibility to provide dispatchable generation, since operators will need to balance the provision of generation with satisfying other water demands. Other dispatchable resources, typically natural gas-fired generation, will be needed to compensate for this shortfall. Currently, the extent of these effects and the conditions under which they occur have not yet been well characterized. There is a need for more modeling and analyses to provide insight into this interaction.

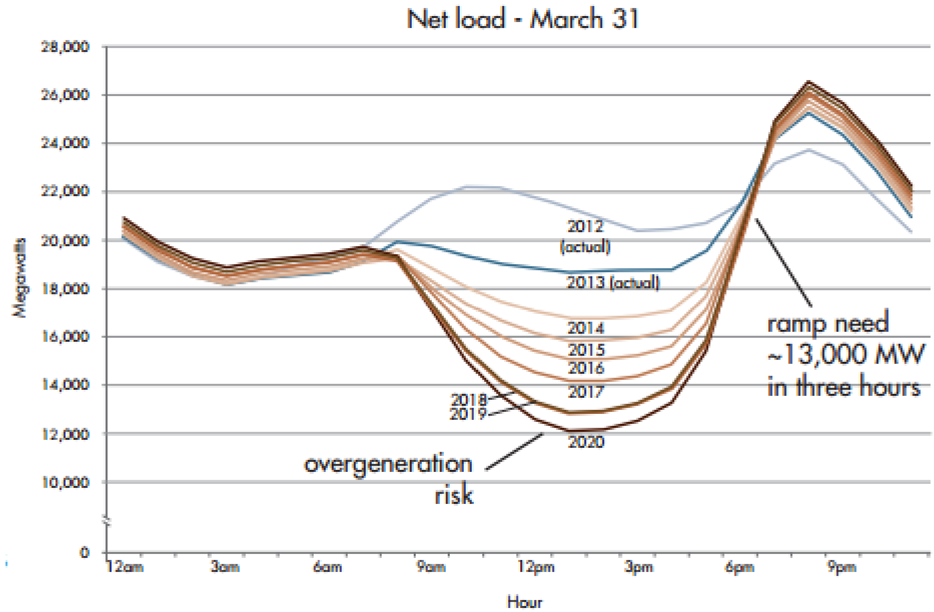
The timing of precipitation and runoff can be significantly altered with climate change as well. For example, in California, climate change is expected to reduce the snowpack that delays runoff from the winter months to the spring and summer months. When rain occurs in the winter months, water will be directly introduced into rivers that provide input to hydropower reservoirs, potentially to the point of overfilling, requiring spillage. This shift in has made hydropower services the most available during the winter when the electric load demand is low in California and these services are not as valuable. Additionally, the inability to store all of the runoff in the winter and the lack of runoff in the spring will cause reservoirs to be depleted during summer months when the electric load demand is high, hindering hydropower contribution when it is most valuable.[16]

The deployment of alternative water resource measures such as desalination, conservation, and water reuse at the local scale can reduce the withdrawals from major surface reservoirs and help maintain reservoir levels for hydropower. This is also an example of how greenhouse gas emission reductions and water resource resiliency are co-dependent.

1.2.1.4. The Duck Curve

The electricity sector is currently undergoing a transformation toward lower carbon fuels. Many types of renewable resources are being deployed including geothermal, hydropower, biomass, biogas, wind, tidal, and solar power. In particular, wind and solar resources development have increased dramatically due to their large resource potential. Wind and solar resources have variable generation profiles, which introduce temporal dynamics into the electricity grid.

16 U.S. Global Change Research Program, Climate Change Impacts in the United States, Washington DC 2014 http://nca2014.globalchange.gov/



A primary example of how the non-dispatchable nature of solar resources introduce temporal dynamics into the electricity grid is California's "duck curve."[17] The net load profile represents the remaining demand that dispatchable grid resources must meet.

Solar power generation occurs in the daytime hours and ramps down quickly during the late afternoon when the residential electric load demand begins to peak. The duck curve is a result of increasing penetrations of solar power generation without additional supporting technologies (i.e. energy storage and demand response), and refers to the shape of the net load profile of electric load demand minus the renewable generation in the system. The net load profile represents the remaining electric load that dispatchable grid resources (such as natural gas power plants) must satisfy to balance total supply with total demand.

Large penetrations of solar causes the net load to be decreased during the daytime, displacing dispatchable power plants. Some of these dispatchable resources are required to remain online for providing reserve capacity. If the sum of renewable generation and the minimum generation from dispatchable resources exceeds the load demand at any given hour, there will be an oversupply of electricity and renewable generation may need to be curtailed or exported. This is exemplified in the previous figure for the year 2020 net load profile.

The ramp down of solar in the late afternoon causes the net load to increase dramatically. In response, dispatchable resources need to come online and increase their power output quickly to satisfy the load. Ramping of dispatchable generators, especially thermally-based power plants, increase wear and tear, decrease efficiency, and increase criteria pollutant emissions. Strategies to address the duck curve include but are not limited to: energy storage, demand response, and dispatchable loads.

17 CAISO, Flexible Resources Help Renewables – Fast Facts, 2013

Water supply-related electric loads can present an opportunity to prevent oversupply and allow usage of renewable energy resources. Current water supply-related loads can be dispatched to respond to renewable generation and smooth the net load profile. For example, water pumping and distribution loads can be shifted to occur during times of high solar generation. Additionally, electric loads from new water supply measures like desalination may be dispatched to respond to renewables and alleviate issues with the duck curve.

1.3. Market and Cost Considerations

An understanding of how water and energy markets interact can provide insight into the implications of policy actions and opportunities for technology.

Markets for energy tend to operate over large spatial areas and are managed by centralized entities. For example, electricity in California is procured by utilities through two primary methods. The first is through direct contracts with power providers, which is typically used for procuring base-load power generation over a set amount of years. The second is through bidding into the California electricity market, which is conducted and managed by the California Independent System Operator (CAISO), which is responsible for managing the transmission system and the transfer of supply to meet utility demands in the state.

In the electricity market, power providers submit bid curves which convey the selling price of different quantities of energy produced from their power plants, while utilities and other load-serving entities (LSEs) submit bids curves, which convey their buying prices for different quantities of energy received. These bids are matched to “clear” the market. These processes are initiated on the day before the energy transfer, and during the trading day in smaller time increments (1-hour, 5-minute) to respond to deviations from the forecasted needs for supply. CAISO sets rules that govern the structure of bids, the types of services (i.e. energy or capacity), and how the market for each type of service is operated. In this sense, the electricity market is managed centrally by one entity, the central market is where all suppliers and load-serving entities participate, and the prices at which electricity is bought and sold are uniform at every time the market is cleared.

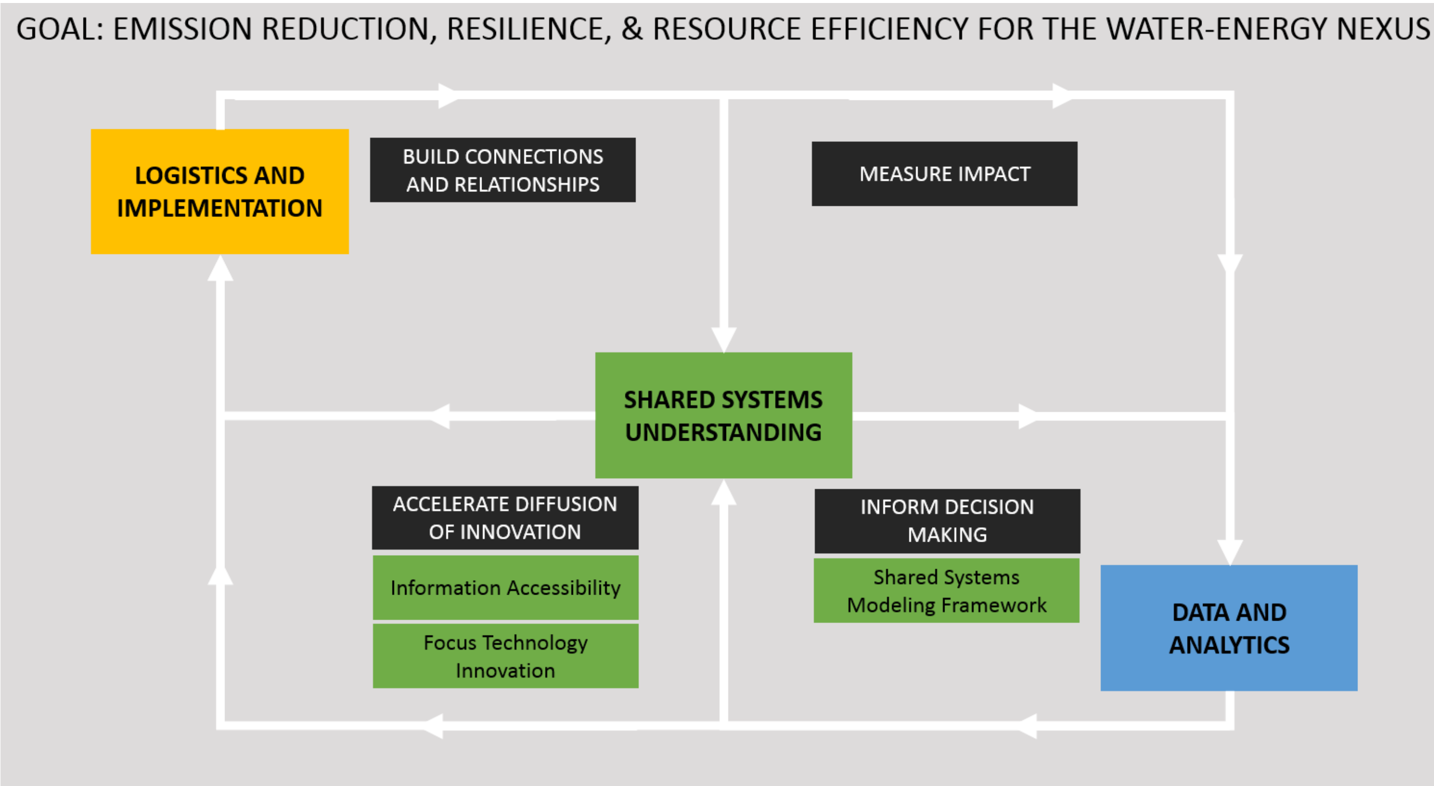
Markets for water are structured and managed differently than those for energy. In California, water utilities typically procure supply directly from local resources or contracted imports, and/or from allocations set by state-level water managers. The current state of water markets in states such as California is meant primarily for the direct trading of water between various owners (such as farmers with water rights or water utilities), not for being the system operator balancing supply and demand. The prices at which water is traded at between these entities.

The trades for water that do occur are not managed by one entity. In California, depending on the location of the trading parties, the date of their water rights, and what facilities are involved, water transfers in the market are facilitated by different government entities. These transfers can take on the order of months to complete, in contrast to the short-timescale nature of energy markets. Therefore, water markets and their corresponding transactions are decentralized and long-term.

These differences in market structure and purpose between water (decentralized and longer term) and energy markets (centralized and shorter term) can pose difficulties for understanding how changes in one system translate to changes to the other system, but are important to consider. For example, the business case of energy-intensive alternative water resources, such as seawater desalination, can be strongly dependent on the cost of the input electricity. The costs of pumping and treating water are also dependent on electricity costs and are incurred by local water utilities. There can also be additional indirect effects. For example, deploying alternative water resource measures can allow hydropower reservoirs to have higher fill levels, allowing hydropower to continue performing grid services and avoiding costs from costly conventional power plants.

Chapter 2 –Shared Systems Understanding

A shared systems understanding is needed to effectively address issues in the combined water-energy system. In Chapter 1, many interdependencies between the water and energy infrastructures were described. These interdependencies, while not comprehensive, have implications for how targeted efforts can effectively address the key challenges for the combined water-energy system.



The action area of Shared Systems Understanding includes three next steps: 1) develop a shared systems modeling framework, 2) facilitate information accessibility, and 3) focus technology innovation. Developments in these areas advance goals for accelerating the diffusion of innovation and informing decision making. Improving shared system understanding also influences the other action areas. Logistics and Implementation is advanced with the institutional knowledge development that a shared systems understanding brings across the energy and water sectors, and Data and Analytics is furthered by informing the development and investment in models of the combined systems.

2.1. Guidelines for a Shared Systems Modeling Framework

A modeling framework that can contribute to a shared systems understanding for informing targeted actions has the following purposes:

- Understanding possible system behavior under potential future conditions.
- Evaluating the impact of proposed targeted actions on the performance of the system in the context of sustainability-related goals.

- Using the gained understanding of system behavior to develop more effective targeted actions for addressing sustainability-related challenges.

It is important to emphasize that it is not practical or necessary to have one all-encompassing tool or model that can capture all of the temporal and spatial scales of the water and energy systems, as models and tools can be built around specific questions, scales, or system characteristics. For example, a shared systems model that operates on a statewide scale will address important but different questions than a shared systems model that operates on the scale of an individual utility territory. These models can and should interact with and inform one another even while their individual deliverables are different. A smaller scale model will have more resolution, which may be more relevant to on-the-ground decisions, while a larger scale model will be able to capture overarching trends and the coordination needed between smaller scale systems to meet sustainability-related goals. Regardless of the spatial scale, a useful framework will:

- **Capture to the extent possible the dynamic physical, technical, and economic links between the water and energy systems and the developments in related sectors (e.g. agriculture)** such that the impact of a change in one system on the operation or performance of the other is captured. This should include resource availability, policy, and technology operation or deployment. For example, if a desalination plant is installed at one part of the system, how does that impact the operation of the electricity system that must support it?

- G**auge the performance of the water-energy system in the context of sustainability-related goals**. For example, GHG emissions of the combined water and energy system must be captured, meaning that if an action reducing GHG emissions from one sector increases it in another such that the total emissions are not reduced, then it should be reconsidered.

The following capabilities are also important:

- **Flexibility to perform scenario analysis.** One of the major advantages of a shared systems model is ability to predict the impact of targeted actions on the performance of the combined system. Therefore, for a shared systems platform to be useful, it should be able to simulate a wide range of configurations that represent these targeted actions.

- **Ability to integrate with other models.** A shared systems model should be able to take inputs from other shared systems models on different scales and produce outputs that may influence them, in part through coordinating metrics. This allows the translation of insights gained at one scale into impacts on another scale, and enables coordination between small and large scale systems.

- **Ability to adapt over time to new insights.** No shared systems model will be able to capture all of the interactions that may be present in the real system upon its initial development, as the purpose of developing and using these models is to discover and identify some of these aspects. A shared systems model should be able to evolve and adapt to incorporate new data as they become available.

Different entities can be suited to fulfill different roles in the development and use of a shared systems modeling framework as follows:

- **Research Universities or National Laboratories** can develop predictive models based on functional relationships between energy and water systems. The models can them inform exploration of dynamics across systems.

- **Regulatory Agencies and Utilities** can provide input into the development and validation of tools to ensure that the modeling framework adequately captures dynamics that have been observed in the real world while maintaining its ability to provide insight into future dynamics. Regulatory agencies and utilities provide insight into policy scenarios.

With the development of a shared systems modeling framework, we will be better equipped to determine how to address key challenges facing the energy and water sectors.

A shared systems understanding perspective can provide insight into how the future conditions affect the behavior of the joint water-energy system. Currently, there are many gaps in understanding how future conditions affect water and energy resource sectors, taking into account their interdependencies. A shared systems modeling framework can allow more complete characterization of the impacts to the system. An understanding of potential future system behavior can help identify potentially undesirable effects and better inform planning for mitigating these effects.

For example, there is a current gap in understanding of projected impacts of climate change on precipitation and water supply in California on hydropower generation. Climate change can potentially impact overall precipitation amounts and the timing of precipitation trends in the state. In turn, changes to precipitation trends can impact the ability of surface reservoirs to store sufficient amounts of water for meeting consumer demands during months of low precipitation. Since many large surface water reservoirs also function as large hydropower plants that provide carbon-free power generation and grid reliability services, lower water storage levels can also compromise hydropower generation as water releases are limited and managed to ensure that the consumer demand is met. This can have implications for the operation and performance of the energy system which will need to be taken into account under future planning.

Currently, a solid understanding of the potential impacts of climate change on hydropower generation is limited. The effects of climate change on water storage and on hydropower generation and energy system operation are still being explored. A shared systems modeling framework can facilitate advanced modeling and analysis to characterize the range of possibilities for the extent of such potential impacts.

2.3. Information Accessibility

Because one of the main purposes of developing a shared systems understanding is to inform future planning and consumer behavior, information accessibility is key. The insights gained from analysis of water and energy system operational data and the outputs of predictive modeling can 1) be applied to guide planning of the evolution of water and energy infrastructures to better meet sustainability-related goals, and 2) inform consumers about potential behavioral changes that can aid in meeting sustainability goals.

Both the water and energy systems are undergoing technological transformations. In the energy system, there is a focus on shifting the primary resource base from fossil fuels to renewable energy resources including wind, solar, geothermal, hydropower, and biomass/biogas and processes to decarbonize fuels. In the water system, there is a focus on diversification of the water supply base and inclusion of supplies that are not as dependent on climate patterns, such as desalination and wastewater re-use. Regarding the latter, limits may exist in terms of the available wastewater for re-use, which will need to be taken into account for water supply planning under climate change.[18]

The deployment of alternative water supply measures has an impact on the four water supply infrastructure loads described in Chapter 1. Water reuse is being deployed to provide water resource security. While the deployment of a given capacity of water reuse does increase energy demand, it may reduce the need for water to be imported into a region, reducing conveyance loads. For example a study for California[19] showed that due to the structure of the water supply infrastructure, the reductions in water conveyance energy consumption outweighed the additional energy consumption of the water reuse processes due to the topography of conveyance systems in the state. The same study showed that thermal desalination, while an option for water resource security, can significantly increase combined water-energy greenhouse gas emissions if these units do not use renewable energy or waste heat. Insights such as these and others are garnered from a shared systems perspective and can be useful for policymakers and utilities who are engaged in evaluating the benefits and detriments of different options for meeting water and energy-related sustainability goals.

The knowledge gained from shared systems analyses can be used to inform consumers about the impact of their behavior patterns, whether beneficial or detrimental, on the combined water-energy system in the context of sustainability criteria. For the purposes of billing by utilities, consumers are typically provided information about their bulk consumption of water and energy over a given billing period at a minimum to justify the charges incurred. Some utilities provide a temporal breakdown of a consumer’s energy usage in combination with their rate structure. This information is used by consumers to understand their energy or water usage and allows them to implement changes in their usage pattern (e.g. operating appliances such as dryers and dishwashers off-peak) to reduce their energy and water costs which ideally also helps each system with meeting some sustainability criteria (e.g. reduced energy usage leads to reduced GHG emissions, etc.)

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18 Tarroja et al, Evaluating Options for Balancing the Water-Electricity Nexus in California: Part 1 – Securing Water Availability, Science of the Total Environment.

19 Tarroja, B., et al., Evaluating options for balancing the water–electricity nexus in California: Part 2—Greenhouse gas and renewable energy utilization impacts. Science of The Total Environment, 2014. 497–498(0): p. 711-724.

A shared systems understanding that maps out how water and energy demand are coupled can expand on the current consumer information paradigm by allowing utilities to provide information about the externalities associated with water and energy use. For example, with an understanding of how energy use impacts water demand of the larger system, an energy utility bill can include information not only on a consumer's energy use, but the water demand elsewhere in the system associated with that energy use. A parallel principle can work for a water utility bill, where information about energy usage associated with a consumer's water use can be provided. Alternatively, the two bills could be combined into one.

This information can allow consumers to be more educated about the couplings between the water and energy systems. The types of data that are needed to determine these couplings between water and energy demand and the opportunities from increased data quality and availability are discussed in Chapter 3.

2.4. Focusing Technology Innovation

Another primary purpose of developing a shared systems understanding perspective is to inform the identification of specific opportunities for technology R&D and policy incentives to enable the combined water-energy system to meet sustainability goals. A shared systems modeling framework can be used to stimulate innovation in two primary ways.

First, the framework can be a **means to evaluate the potential impact of emerging innovations in technology** in improving the performance of the system with respect to sustainability criteria. The benefit of having a shared systems modeling framework is that it allows a more direct measure of whether an innovation has a beneficial systematic impact. Currently, determination of the benefits from emerging innovations is often based on extrapolation of performance data or characteristics at small scale to apply to large-scale systems. This approach has varying levels of accuracy, however, as the scaling up of an emerging innovation can often have unforeseen indirect effects that can be beneficial or detrimental.

A major knowledge gap where this application can be useful is evaluating the opportunities for water and energy related savings in the agricultural sector. While agricultural water usage has lower energy intensity compared to urban water usage, the former represents a much larger proportion of the overall water consumption in states such as California. Therefore, technologies and management strategies for improving agricultural water use efficiency present opportunities for improving the performance of the joint water-energy system. Currently, however, an understanding of how improvements in the agricultural sector can contribute towards water-energy sustainability criteria is not well established. A shared systems modeling framework can be used to evaluate the effectiveness of these improvements in this context.

Second, the framework can also be used to **identify aspects of the system that need improvement to increase the robustness of strategies to meet sustainability targets**. This could be carried out using sensitivity analyses in planning studies, where the sensitivity to increased capabilities for different technologies (i.e. efficiency, flexibility, etc.) is analyzed. Outcomes of analyses can include but are not limited to 1) establishment threshold values for technology characteristics beyond which a technology is viable or beneficial, or 2) identification of key changes in system operation that are needed to better support other technologies.

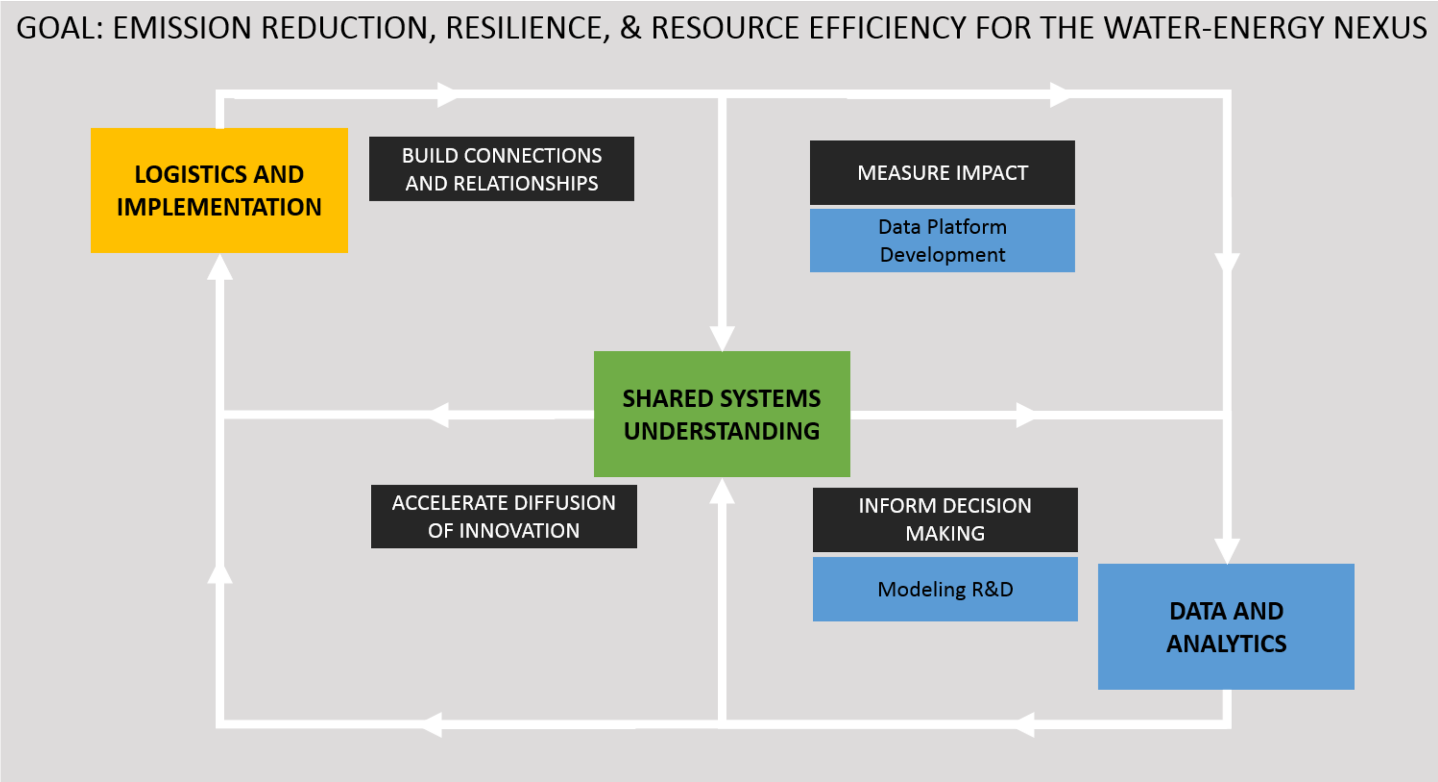
For threshold value establishment, consider a scenario where membrane desalination is planned as a significant part of the technology portfolio for providing water resource security due to limitations on the capacity of other measures, but the energy usage of these systems causes water costs to be too high. A shared systems sensitivity analysis on membrane desalination plant efficiency can determine the improvements in energy efficiency for this technology that are needed to reduce energy usage to a level that yields reasonable water costs. If this threshold value falls in a technically feasible range (i.e. it does not violate the physics that limit process efficiency), attention and targeted investment can be given towards research and development of novel technologies that can help reach this goal.

For key system operation change identification, consider the same scenario with high capacities of membrane desalination. The temporal inflexibility of desalination plant operation can hinder its ability to utilize variable renewable power generation, causing carbon emissions related to desalination to pose difficulty in meeting GHG emissions reduction goals. A shared systems sensitivity analysis can simulate what the potential improvement in carbon emissions reduction could be if the electric loads required by desalination plants could be operated in a dispatchable fashion. If this benefit is found to be significant, attention and investment can be given to research and development into technologies and control algorithms for building this capability into future membrane desalination plants.

Overall, a shared systems understanding and the corresponding modeling framework can be a powerful tool to inform innovations to most effectively address sustainability-related goals related to the water-energy nexus. Research and development investment and policy support can be targeted at opportunities that can enable the larger system to move towards sustainability goals in an efficient and low-cost manner.

Chapter 3 – Data and Analytics

The shortage of high-quality, granular, easily accessible data on water and energy systems operations often prevents effective joint-systems analysis and inter-agency cooperation. Workshop discussions supported and extended findings from Heather Cooley's *Water-Energy Synergies: Coordinating Efficiency Programs in California*, a Pacific Institute report that quantified perceived barriers to inter-agency cooperation. Some of the most significant barriers are directly or indirectly related to the issues of operational data, with "poor quality or insufficient data to quantify water and energy savings" being ranked as a moderate or significant barrier by 69% of industry survey respondents in the Pacific Institute's report. This chapter will expand upon the current state of system operation data collection, the opportunities and motivations for improved data collection, quality, and accessibility, and recommendations for how to best leverage data to encourage water-energy co-optimization and collaboration.



The Data and Analytics action area of the framework developed in this report includes two next steps: 1) data platform development and 2) modeling research and development. With improved analytics, system planners and regulators can make more data-driven decisions and better measure the impact of those decisions. Situational awareness facilitated through new data-collection technologies helps operators to develop shared systems understanding. Additionally, creating a data platform that standardizes data collection can simplify logistics for program development and verification, as well as provide information on the logistics of collaboration across the water-energy nexus.

3.1 The Current State of System Operational Data

Water and energy utilities both collect data on individual customer consumption and system-level characteristics. Energy utilities need to collect more detailed and frequent data about customer consumption and system status due to the differences in the management timescales of electricity and water infrastructure. The overwhelming majority of energy utilities in California collect electricity consumption data at hourly frequencies, while most water utilities collect volumetric totals at their billing frequency, which is typically on the order of one month. Utilities use this data at the customer level for billing purposes and internally for operations purposes, but rarely make this data publicly available. In addition to consumption data, energy utilities typically collect load, voltage, and frequency data throughout the transmission and distribution grids. Many water utilities do not collect similar data, though some monitor pressure across distribution systems. Regulatory institutions, such as the California Public Utilities Commission, also collect high-level and summary data from utilities and third parties to monitor compliance and inform rate cases. There are three main types of operational data collected in the water and energy industries: customer point of connection (PoC) meter data; submetering; and transmission, conveyance, and distribution system-level input/output data.

3.1.1 Customer Point of Connection Metering

The recent rollout of two-way communicating sensors, including customer-level “smart meters”, in the energy industry has had drastic impacts on the way customers, power providers, and third parties interact with each other and the flow of energy between these groups. Smart meters have been implemented in more than 50% of households across the country, and have paved the way for improved customer-facing programs, advanced technologies, and improved system understanding. Advanced metering infrastructure (AMI) connects these smart meters to powerful data analytics and management tools, enabling utilities and customers to explore and better understand energy usage patterns. Smart meters also enable more targeted, effective utility programs. For example, time-of-use (TOU) electricity pricing, which incentivizes customers to shift peak energy consumption to off-peak hours when stress on the grid and wholesale power prices are lower, is only possible when hourly or sub-hourly energy consumption data is collected at the customer level. Other electricity programs enabled by smart metering include demand response (DR), which requires baseline determination and load shed verification only possible with smart metering, and the suite of customer-targeted services made available through web portals, including usage visualization, high-use alerts, blackout tracking, and budget setting.[20]

Smart meters are far less common in the water industry. Due to lower revenues and longer timeframes at which water infrastructure operates, smart water meters have not yet gained significant traction, and utilities often struggle to justify the capital costs of replacing traditional meters and billing systems. This means most customer-level water consumption is measured monthly or even less frequently (in some places as rarely as every six months), often by hand, and only for billing purposes. Traditional water meters typically measure water consumption in coarse units of centrum cubic feet (CCF) or thousand gallons and with very low precision. This lack of granular and accessible

20 Institute for Electric Innovation. “Utility-Scale Smart Meter Deployments: Building Block of the Evolving Power Grid”. September 2014.

water data leads to poor customer awareness and insufficient understanding of their own consumption patterns. For example, a survey of East Bay Municipal Utilities District (EBMUD) customers found that 60% of single-family customers think they use less than 50 gallons per day (gpd), while the average use in EBMUD was well over 200 gpd.[21] The few large-scale smart water meter installations in the water sector have demonstrated increased customer awareness, easier and more regular billing, and automated leak detection.[22] In the agricultural sector, customer water metering is less common than the municipal sector. This is mainly due to lenient or nonexistent groundwater monitoring regulations and resistance to water use reporting.

3.1.2 Submetering

While customer PoC metering is a crucial set of operational data, particularly for utilities and small customers, in-facility submetering can be an enormously valuable resource, contributing to system understanding operations and process optimization. Submetering can be implemented in a number of different sectors of the water-energy nexus, including residential homes, commercial buildings, and other large facilities, especially those for the production of electricity and natural gas and the withdrawal, treatment, and disposal of water.

While no cost-effective residential submetering device is yet available for water, some electricity monitoring and management systems have been developed and marketed to the residential sector. These types of devices tap into the growing Internet of Things (IoT) market, giving homeowners more information and control over household devices.

In the commercial sector, a growing number of buildings use building management systems that monitor energy use, control end uses, and centralize data management. One of the primary drivers for this market is the desire to reduce demand charges that arise from high peak loads. Submetering within a building, particularly offices, is growing in popularity, with individual workstations on separate submeters and/or controls[23]. Submetering of water use in the commercial sector is not as common, with most investment focused on overall water use efficiency.

The production of drinking water, electricity, and natural gas, as well as the disposal of wastewater, are water- and energy-intensive processes that have lately come under increasing study and are candidates for submetering. While much ongoing research targets novel and improved processes, in practice, many plant operators do not have thorough submetering of process-level energy and water inputs and outputs. For example, over the course of the workshop, representatives of the wastewater treatment sector commented that: (1) any submetering of water quality is done only for regulatory or permitting reasons, (2) the energy and water flows within a treatment system are often poorly understood, and (3) operational efficiencies could most likely be achieved with basic electricity and/or water submetering of processes. Industry pilot projects support this claim, with a range of wastewater

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21 David Wallenstein. “AMR as a Water Conservation Tool”. http://www.metering.com/wp-content/uploads/Metering%20America%20Wallenstein1.pdf

22 E. Ritchie. “AMI Success Stories: Leveraging technology for savings and efficiency”. Water Efficiency, Vol. 10, No. 4, pp. 13-21. June 2015.

23 Ian Metzger, Alicen Kandt, and Otto VanGeet. “Plug Load Behavioral Change Demonstration Project”. August 2011.

treatment plants in New York finding untapped energy savings potential in a number of systems, in particular aeration tanks.[24]

3.1.3 Transmission, Conveyance, and Distribution System Monitoring

The systems that support the transmission, conveyance, storage, and distribution of water and electricity are monitored at varying levels across the nation. To name a few examples at the national level, the North American Electric Reliability Corporation (NERC) has grid reliability reporting requirements, the majority of generators in the United States voluntarily maintain generation histories through the NERC Generating Availability Data System (GADS), and the United States Environmental Protection Agency (EPA) maintains drinking water standards and testing schedules. State Public Utilities Commissions (PUCs) can have drastically different reporting standards. These regulatory reporting standards represent the minimum required monitoring a utility or third party must implement for their system. Some utilities, balancing areas, water districts, or other entities involved in the transmission, production, and distribution of energy and water choose to install more advanced monitoring systems than necessary in order to capture the improved operational efficiencies made possible by more granular operational data and advanced analytics.

3.2 Opportunities and Motivations for Improved Data Collection

While both energy and water utilities are typically conservative regarding emerging technologies and data privacy and security, many stakeholders at the workshop stressed the need for advanced data collection at all levels of system operations. Justifications for improved data collection included: improved energy and water efficiency, lower operating costs, improved system resiliency, more accurate forecasting, more reliable fault detection, and more accurate system modeling capabilities.

3.2.1 Advanced Metering Infrastructure

While advanced metering infrastructure (AMI) is widespread in much of the electric industry, it is struggling to gain momentum and market acceptance in the water sector. AMI is a hardware and software architecture that connects a network of advanced two-way communicating sensors and meters with a central data management system, allowing utility operators to utilize advanced analytical techniques on real-time data to improve system operation. Some of the successes and benefits of AMI in both sectors are discussed in subsection 3.1.1 Customer Point of Connection Metering. Since smart meter and AMI penetration is so high in California, the amount of data being collected by electricity utilities is immense. The water sector could similarly benefit from deployment of AMI.[25]

3.2.2 Pilot Programs

Pilot programs run by both water and energy utilities have the potential to provide a wealth of data to other utilities considering or actively pursuing similar programs and goals. The types and quality of

24 Stearns & Wheler LLC, and NYSERDA. “Energy Performance through Submetering Wastewater Treatment Plants”.

25 Pacific Institute. “Metering In California”. September 2014.

data collected by pilot studies varies widely based on the type, scale, and goal of the pilot study itself. Additionally, since most pilots are designed to help inform a utility's internal operations, price structures, or infrastructure investments, many are evaluated in internal reports. Data collected and lessons learned are typically not shared. However, academic studies and externally funded pilots typically result in publicly released reports.[26]

For example, pilot programs studying customer sensitivity to TOU electricity prices often collect AMI data and compare how on- and off-peak consumption patterns change. This type of pilot may summarize its findings as customer price elasticity or extrapolated peak load reductions. Other pilots may demonstrate technology capabilities and estimate infrastructure costs. Others may collect survey data on customer behavior, preferences, etc. As the technological, regulatory, environmental, and business environments that utilities operate in become increasingly complex, research, development, and demonstration projects are becoming crucial elements to the survival and success of enterprises in the water-energy nexus.

3.2.3 Regulatory Support

Research has shown that there is embedded energy in treated and transported water, and that this embedded energy can be significant;[27] however, the exact relationship is still poorly understood, and even more poorly quantified. What is understood about embedded energy in water is its inherent variability; surface water supplied through gravity systems can have a fraction of the embedded energy of groundwater or desalinated water. The California Public Utilities Commission (CPUC) attempted a statewide estimate of embodied energy in water in 2005,[28] however lacked the data and methodology to make precise estimates. Since then, the CPUC has pursued the production of an embodied energy calculator, which will aid utilities in more accurately quantifying embedded energy reductions from water efficiency programs. Historically, there was no way to integrate the embedded energy benefits of joint water-energy programs into the cost-effectiveness calculations. Since investor owned utilities (IOU) in California are accountable to the CPUC, this inability to claim embedded energy benefits has been a barrier to more widespread joint programs. The proposed calculator will enable energy and water utilities to quantify these benefits, which should improve the perceived cost-effectiveness of joint water-energy programs, leading to more such programs.[29]

Regulatory opportunities also include mandated data collection efforts with the goal of supporting and enabling more robust long-term resource management. For example, California's recently effective Groundwater Sustainability Act focuses on more sustainable resource management by giving local, regional, or state agencies the authority to manage groundwater. The Act requires the agencies to develop of data collection and monitoring strategies to quantify groundwater basins' short and long-term trends and resolve water rights disputes. Similar efforts can provide utilities, end-users, and

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26 Jennifer Potter, Stephen George, and Lupe Jimenez. "Smart Pricing Options Final Evaluation". September 2014.

27 GEI Consultants, and Navigant Consulting, Inc. "Embedded Energy in Water Studies, Study 1: Statewide and Regional Water-Energy Relationship". August 2010.

28 California Energy Commission. "California's Water-Energy Relationship". November 2005.

29 Navigant Consulting, Inc., and GEI Consultants. "Water/Energy Cost-Effectiveness Analysis". April 2015.

regulators the informational resources to encourage and improve joint resource management in the water-energy nexus.

3.2.4 Shared Systems Understanding

Advances in the resolution (i.e. spatial, temporal) and breadth (i.e. types of data) of operational data in both the water and energy systems is critical for developing the shared systems understanding necessary to make more informed planning decisions for the evolution of the combined water-energy system. Access to databases of operational data will perform two key functions for the development of the shared systems understanding presented in the previous chapter.

First, analysis of operational data will allow key couplings between the water and energy systems to be identified, their sensitivities, and potential opportunities. For example, temporally resolved data on customer demand, pumping loads, and electricity prices can indicate whether pumping energy falls within on-peak or off-peak hours. This can help identify electricity rate structures that better accommodate water demand patterns and reduce the cost of providing water. In addition, opportunities for operating distribution pumping as a dispatchable load to better align with times of low electricity prices or to follow variable renewable generation can be explored.

Second, identification of key couplings from operational data will form the basis on which models of the combined water-energy system for a given spatial scale will be developed. This data will inform the development of water-energy system planning models by verifying the behavior and improving predictive capability. The model development and verification will enable more confidence in the results of exploratory studies for system improvements and optimization. Additionally, as new data becomes available in terms of type or resolution, they will be used to update the models and planning tools to ensure that their predictive capabilities evolve with real systems.

Overall, many of the benefits of having a robust shared systems understanding as described in the previous chapter require a sound foundation of operational data to illuminate the key couplings between the water and energy systems at different scales. Therefore, a focus on obtaining sufficiently resolved operational data types and a sufficient breadth of data should be priorities. The specifics of what constitutes sufficient resolution and breadth will be an ongoing topic of discussion for different scales of systems, as will the standardization of operational data. Additionally, this data needs to be made accessible to the entities that will use them, which is described in more specificity in section 3.3.

3.2.5 Improved Hydrologic and Climate Model Integration Data

Improved characterization of the hydrologic and climate systems that impact the water and energy sectors is also important to develop robust long-term resource management strategies. Climate changes, including altered precipitation distributions and changing renewable energy potential, can reduce water resource security, increase variability in energy supply, and reduce hydropower capabilities. More accurate hydro-climate models capable of exploring these changes at the regional and local scales that are directly integrated with water and energy utility system planning models, will improve utility resiliency as the effects of climate change worsen.

3.3. Data Platform Development

In addition to the need for the collection of more high quality data on system operations, stakeholders highlighted the lack of easily accessible data. For understanding system operations by utilities, government agencies, and researchers, high quality data should be accessible to all parties while stakeholder privacy and system security are also protected and maintained. Accessibility of data can be broken down into two main components: availability and standardization.

Two of the primary barriers to making most operational data publicly accessible are the issues of privacy and security. Customer fears of identifiability and perceived invasion of privacy make customer-level meter data difficult to obtain. Developing an accepted methodology for anonymizing data, and then a secure architecture and central repository for anonymized datasets would enable utilities, companies, researchers, and the public to leverage large datasets in a way akin to the DOE Buildings Performance Database. Some level of agreement will be needed for the types of data that are publicly released versus made available by request. Publicly available data becomes far more useful to a wider audience when there are standardized data formats accepted by industry. Disparate data formats increase the transaction costs to utility analysts, researchers, and regulatory institutions, by requiring personnel in different entities to spend a significant amount of time and resources on interpretation of datasets and conversion to integrate with relevant models.

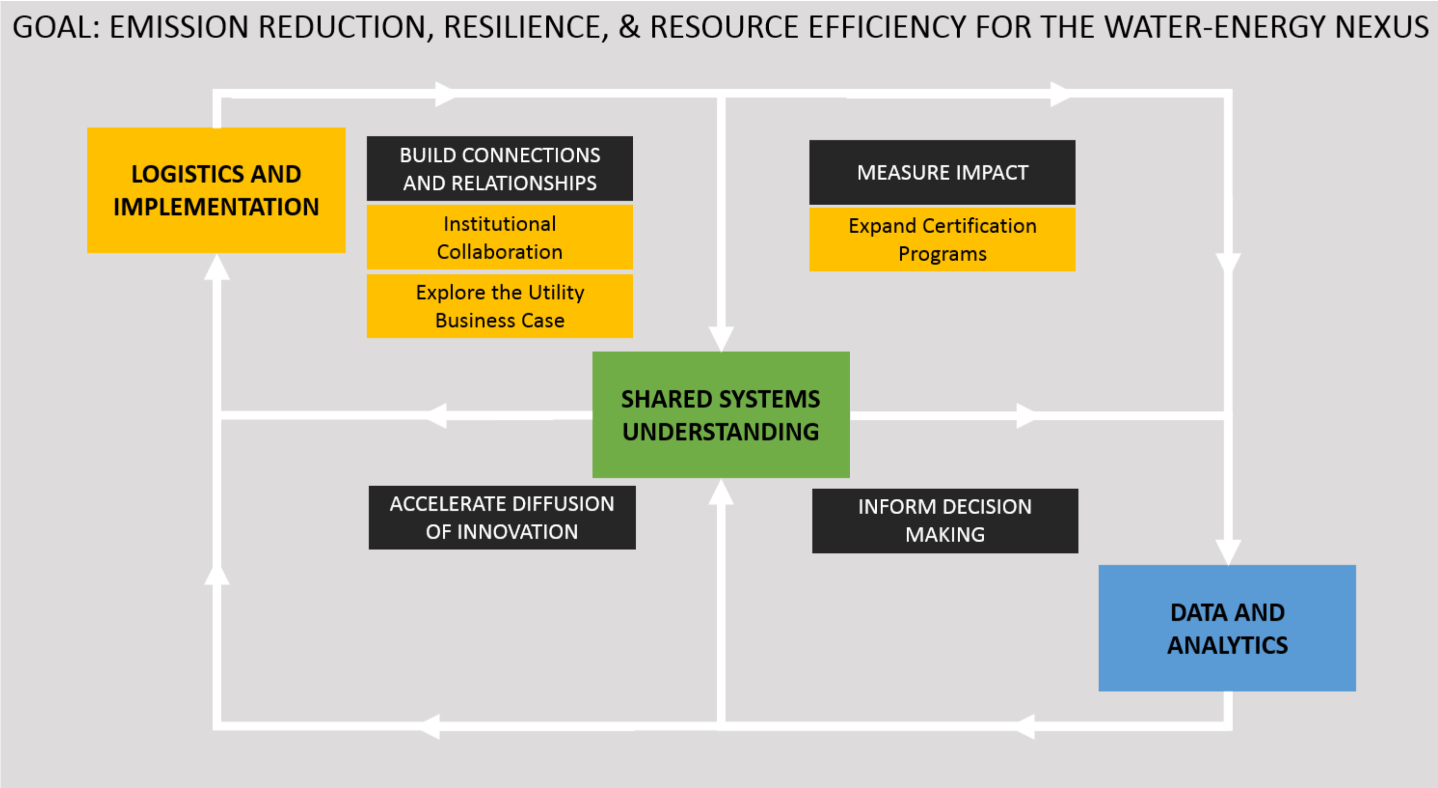
A standardized data format for a given data type in terms of units and relevant references for the measuring methodology (e.g. reference pressure) will streamline the retrieval, analysis, and integration of relevant data types into shared systems models. If disparity exists in measurement methodology between different utilities or other entities, a clear standard for conversion between data types should be established. This will expedite the development of system understanding and the identification or exploration of actions needed to address known issues and plan for potential issues.

3.4. Modeling Research & Development

As stakeholders across the water and energy sectors begin to utilize the great wealth of data made available by more cost-effective and ubiquitous sensors, improved reporting standards, and the recommended water-energy data platform, developing improved and integrated models and analytical tools can greatly improve the efficacy of decision-making within the water-energy nexus. These models and tools should span geographic scales, from building-level integration of water-energy management to regional integrated resource planning, and temporal scales, from hourly and daily utility joint operations planning to multi-year resource availability forecasting. Creating such models of water and energy systems will require collaboration between stakeholders in both sectors, including utilities, regulatory entities, researchers and academics, and customers to improve both the planning and operation of energy and water systems.

Chapter 4 – Logistics and Implementation

Water and energy utilities exist in drastically different regulatory regimes that have diverse public interest and stakeholder engagement concerns. Collaboration efforts have mostly been from the bottom-up, around specific projects to address the directly identifiable co-benefits between energy and water utilities. These projects develop a base of working trust across sectors, and create a foundation for further communication and future collaboration. Coordinating water and energy efficiency efforts remains an issue due to limited funding, coordination challenges, program evaluation, and lack of metrics to quantify savings.[30]



The Logistics and Implementation action area of the framework developed in this report includes three next steps: 1) building institutional collaboration, 2) exploring the utility business case, and 3) expanding certification programs. Development in these areas most directly advances goals for building connections and relationships, and measuring impact. Advancement in these areas also helps develop: 1) a shared systems understanding as experts from both sectors interact, and 2) improved data analytics, standards, and collection methods.

4.1. Institutional Collaboration

Logistical barriers for collaboration between the water and energy sectors still exist, despite numerous efforts to surmount them. Historically, energy and water utilities in have not had strong

30 Cooley, H. and K. Donnelly, Water-Energy Synergies: Coordinating Efficiency Programs in California. 2013, Pacific Institute.

working relationships. This can limit the ability to initiate collaboration as the correct people to contact are not known, and the benefits of collaboration are initially uncertain. While examples of good working relationships exist, the benefits of these relationships are not as visible to the general industry in both water and energy sectors. Potential opportunities discussed during the workshop included the development of frameworks and methodologies for cost allocation, shared system planning tools, a searchable data and information repository, pilot projects, and increasing dialogue with the agricultural water sector.

Water and energy entities use different terminology, and similar concepts or terms can have different meanings to different sectors. For example, reliability in the context of water supply refers to storing sufficient quantities of water in reservoirs to weather potential dry seasons, whereas in the context of an electric utility it refers to having sufficient reserve generation capacity to survive a contingency event in the system or compensate for short- and long-term errors in demand and generation forecasting.

The development of common frameworks and methods for allocating costs and benefits between entities can help utilities with joint project planning, particularly around indirect energy and water savings. This could help energy utilities to invest in water utility efficiency improvements by clearly mapping out the energy benefits of water technology innovations. The further development of shared systems tools for identifying these projects for utilities in overlapping territories would be beneficial to expanding these efforts. For example, the Western Electricity Coordinating Council (WECC) has incorporated water availability into their tools for transmission planning.[31] Further development of carbon intensity of water resources would help system planners further coordinate efforts across sectors.

Additionally, it is important to increase the visibility of successful projects and collaborations within the water and energy utility industries in order to distinguish worthwhile investments. Collecting information on the primary sources for funding in water-energy projects, and what they funded, would be beneficial to potential program organizers. The development of a centralized, accessible information base for mapping the organizational structure of entities in the water and energy sector, the vocabulary of each sector, lessons learned, funding opportunities, and existing initiatives would be beneficial for stakeholder coordination efforts. This could be wiki-based, like the Regulatory and Permitting Information Desktop (RAPID) toolkit, which is designed to improve collaboration on processes, permit guidance, regulations, contacts, and other relevant information for renewable energy projects.[32] A similar information base for water-energy projects would be valuable in bringing personnel from the different sectors up to a common level of understanding in order to streamline projects that address both water and energy challenges. This data repository in combination with the

31 Environmental and Cultural Considerations. [cited 2015 August 3]; Available from: https://www.wecc.biz/TransmissionExpansionPlanning/Pages/Environmental-and-Cultural-Considerations.aspx

32 RAPID: Collaborating on Regulatory Processes for Renewable Energy Projects. [cited 2015 August 3]; Available from: http://en.openei.org/wiki/RAPID

development of shared systems tools would enable exploration into areas which have the most benefit per unit of investment.

4.2 Expand Certification Programs

As understanding improves between the energy and water sectors with information sharing and shared institutional knowledge development, opportunities for implementation of programs for water and energy resource management can be further expanded.

4.2.1 Program coordination in California

Pilot projects and programs help to initialize dialogue between the energy and water sectors and establish trust and working relationships between the energy and water sectors. They can also help to inform a utility's internal operations, price structures, or infrastructure investments. Additionally, as mentioned in Chapter 3, they can provide data that can inform system design, product development, and customer engagement.

Water and energy efficiency and certification programs require coordination among a diverse set of stakeholders. In California, collaboration efforts between the State Water Resource Control Board (SWRCB), the California Energy Commission (CEC), the California Air Resource Board (CARB), and utilities can be a logistical challenge for governance and reporting to assure that programs are meeting the agencies respective goals. Despite challenges, there has been significant progress in the state in recent years. A report by the Pacific Institute highlighted joint water and energy efficiency programs in California which have overcome logistical barriers.[33]

Regulatory guidance can significantly influence program development and coordination efforts. For example, coinciding regulations from the California Public Utility Commission (CPUC) requiring utilities to examine embedded energy savings associated with water in 2006, and the San Diego County Water Authority (SDCWA) Board to coordinate efforts to implement water efficiency programs in 2007, promoted the SDCWA and the San Diego Gas & Electric (SDG&E) to develop three pilot programs: comprehensive water/energy audits, a landscape irrigation management program, and a recycled water program.

Combining existing programs can help to simply customer interaction and expand program reach. For example, Pacific Gas and Electric and a number of Bay Area water utilities collaborated on developing a High-Efficiency Clothes Washer Rebate Program,[34] which brought together a number of preexisting and uncoordinated efforts from the individual utilities.

These programs illustrate how regulatory coordination as well as program coordination are important for promoting energy and water savings. While many projects in California are good examples of coordination, they also point out lingering issues with funding, scalability, performance evaluation,

33 Cooley, H. and K. Donnelly, Water-Energy Synergies: Coordinating Efficiency Programs in California. 2013, Pacific Institute.

34 High-Efficiency Clothes Washer Rebate. [cited 2015 August 3]; Available from: http://www.pge.com/includes/docs/pdfs/shared/saveenergymoney/rebates/clotheswasher_application.pdf

and jurisdictional barriers. For example, one of the challenges with the SDCWA and SDG&E programs is with the calculation of energy savings resulting from water conservation measures. However, recent efforts have resulted in the CPUC water-energy calculator, which aims to address these very issues.[35]

4.2.1 Certification Programs

As shared system tools and data collection and quality are developed, coordination, implementation, and evaluation become easier and can enable the expansion of conservation certification programs. Specifically, through verification and evaluation after project completion, cross-sector savings can be more fully understood, allowing better allocation of resources and targeting of future program development.

As analytic tools improve, it is important to move from certification programs that use a simple "score card" method to one that includes system analysis and operational performance in order to take into account indirect water or energy savings. Barriers to coordination vary significantly across the industry, in part due to the diversity of entities and topologies involved. Insufficient cross-sector communication makes transferring funds and improving data accessibility problematic, which can inhibit program development and verification. Separate conservation certification programs exist for certain parts of the water and energy sectors, such as EPA's Energy Star, Water Sense, and the U.S Green Building Program's Leadership in Energy and Environmental Design (LEED). And while the LEED certification has some consideration for water, it is based on a score card, which doesn't fully account for the more complex interactions between energy and water systems. These certifications can be extended to take into account projected savings at commissioning and measure/verify actual savings after the fact in order to make comparisons. Measuring program impacts can also improve understanding of the long term effects of the programs, inform potential program development to improve efficiency over time, and provide information to system designers on the life cycle of their systems. Indirect embedded energy and water are often out of the control of the builder and will vary from location to location; an alternative approach may be to emphasize different factors in different regions, based on regional water availability and embedded resources. This regional emphasis can help build operational performance understanding.

Existing programs, such as those mentioned above, can play important roles in benchmarking and evaluating performance standards that can help future development. However, lack of data and shared systems understanding can inhibit the allocation of costs across initiatives and create difficulties when accounting for benefits.

4.3. Explore the Utility Business Case

Developing understanding of business cases, from a utility's perspective, of where it makes sense to do water-energy related projects considering both the short and the long term can help support

35 Water-Energy Calculator v1.04, 2015, California Public Utilities Commission

conservation efforts. This development will also help to identify potential gaps in investment that Government programs could address.

Rate making differences across the sectors are important as well. Implementation will vary, depending on whether or not utilities are able to recoup costs for investments, and how resource efficiency is factored into their business models. For example, in the energy sector, while most utility cost are variable and change in proportion to the amount of power sold, distribution and custom service costs are not variable. Thus, reductions in sales (through energy efficiency) can lead to a greater reduction in revenue than cost. For IOUs, which aim to maximize returns to shareholders, this can be a problem, leading some utilities to "decouple" sales from revenue so that as efficiency is improved, revenue does not go down. Utilities that operate on a non-profit basis might not find decoupling necessary as they have more flexibility to adjust rates on a timely basis.[36] Similar issues with revenue reduction can occur with water-efficiency programs. For water utilities, while conservation programs that reduce water sales and revenue in the short term can result in cost savings in the long term (forestalling capacity expansions, prolonging acquisition of additional water sources, etc.), the short term can be a struggle when costs stay relatively fixed.[37]

Utilities are structured around providing their core service (water or energy) and generally do not consider combined water-energy savings. For example, processes that save water can sometimes come with higher energy demands. California energy utility investments in the water-energy nexus are primarily focused on direct GHG emissions reductions due to the scope of current regulatory policies, which come primarily from end-use efficiency improvements for heating and cooling water. Under the current regulatory context, there is a gray area around indirect GHG benefits (e.g. lower emissions due to reduced water pumping) as a justification for funding. The physical disconnect between where the water is conserved and where energy is reduced makes it unclear which utility should fund the conservation.[38] The diversity of funding sources has implications for cost allocation and project evaluation. For example, one participant noted that the CPUC and the Department of Water Resources have varying methodologies for determining rate payer benefits. Additionally, while pilot projects are incredibly useful in exploring water-energy efficiency improvements, funding between programs becomes challenging when funding cycles do not align.

Water resources are legally managed through a complex system of water rights (and transactions regarding the transference or sale/lease of these rights) between different entities. Issues regarding the jurisdiction over water resources can hinder attempts at optimizing the systematic allocation of those resources to best address water-energy needs. For example, the agricultural and urban water sectors are governed separately and most of the energy-related activity has focused on the urban water sector with agricultural users typically not being included in the dialogue and decision-making.

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36 American Public Power Association. "The Effect of Energy Efficiency Programs on Electric Utility Revenue Requirements." 2010. http://www.publicpower.org/files/PDFs/EffectofEnergyEfficiency.pdf

37 Water Research Foundation. "Knowledge Portals: Utility Finance Revenue Frequently Asked Questions." http://www.waterrf.org/knowledge/utility-finance/revenue/Pages/faqs.aspx. Accessed 12/3/15.

38 Cooley, H. and K. Donnelly, Water-Energy Synergies: Coordinating Efficiency Programs in California. 2013, Pacific Institute.

Opportunities for identifying water-energy co-benefits in agriculture have been hindered by a lack of monitoring and management of agricultural water use – much of which is often self-supplied by streams or aquifers to which farmers have appropriation rights to use. Historically, monitoring is difficult in these areas due to heavy reliance on unmonitored local groundwater sources, or is opposed by resistance to government oversight, and thus paints an incomplete picture. On the other hand, the urban water sector is easier to monitor and track, being more tightly managed than the agricultural sector, which has less embedded energy per unit of water. Unfortunately, the amount of water used the agricultural sector is much larger, with the agricultural sector using about three times more water on average nationally.[39] Thus, large potential improvements have been left unexplored. However, recent regulation in California is focused on improving this opportunity disparity. Specifically, California's Sustainable Groundwater Management Act (SGMA), enables local agencies to develop and report data necessary to sustainably manage groundwater basins and sub-basins and create management plans.[40]

39 U.S. Department of Energy. "The Water-Energy Nexus: Challenges and Opportunities." June 2014. http://energy.gov/downloads/water-energy-nexus-challenges-and-opportunities

40 State of California. "Sustainable Groundwater Management". http://groundwater.ca.gov/. Accessed 1/15/16. For an easy to read version of the legislation:
http://groundwater.ca.gov/docs/2014%20Sustainable%20Groundwater%20Management%20Legislation%20_with%202015%20amends%2011-10-2015_clean-2.pdf

Chapter 5 – Conclusion

5.1. Framework Summary

With the overall system goals of emission reduction, system resilience, and resource efficiency, this report offered three key action areas of focus for future development in the water-energy nexus: Develop and Apply Shared Systems Understanding, Data and Analytics Development, and Logistics and Implementation. As illustrated in the figure below, these areas all impact one another, and thus, development in one area can help improve all the others, while stagnation in one can inhibit advancement in the others to some extent. Besides the overall system goal of reduction, resilience and efficiency, four sub goals which help accelerate development include: Build Connections and Relationships, Measure Impacts, Accelerate Diffusion of Innovation, and Inform Decision-Making. These goals are supported through the eight next steps described in the report, which are summarized as follows:

Shared Systems Understanding. A shared systems understanding that accurately simulates the behavior of the combined water-energy system and its sensitivities to proposed actions will be valuable to inform decisions and actions at the energy-water nexus.

- **Shared Systems Modeling Framework.** A shared systems modeling framework will help to facilitate building institutional knowledge and relationships between water and energy infrastructure, markets, and regulation.
- **Information Accessibility.** Information sharing at multiple scales across utilities and with customers can improve systems understanding.
- **Focus Technology Innovation.** Knowledge gained from shared systems understanding can be used to promote energy and water efficiency innovations by strategically identifying technology development needs, forming a basis for targeted investments in R&D.

Data and Analytics. High quality data on water and energy system operation needs to be gathered to inform the development of shared systems models and be organized, e.g., in a federated manner, to be accessible to stakeholders.

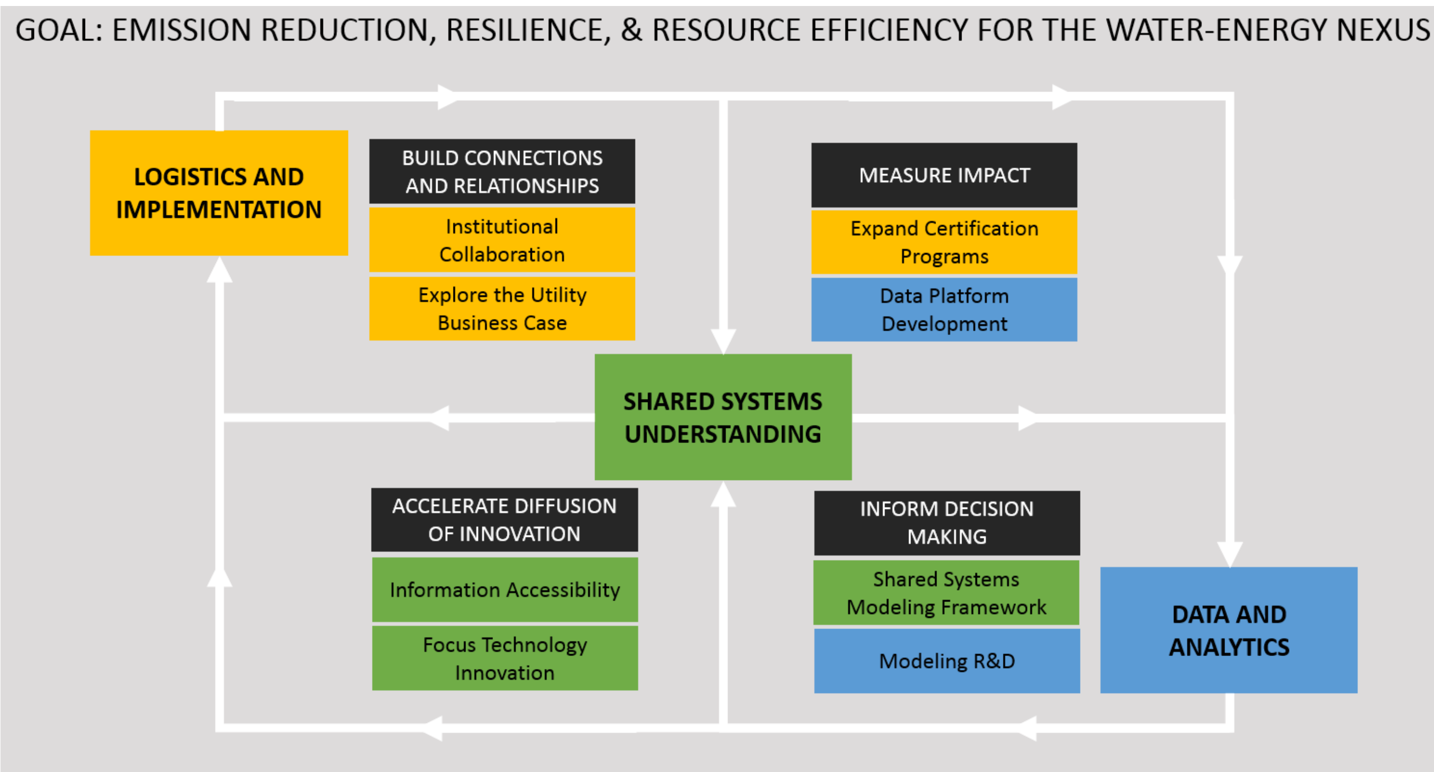
- **Data Platform Development.** A data platform is needed for water and energy utilities' operations that protects personal and proprietary data, aims to improve data accessibility and interoperability, fills data gaps, and informs data quality improvements and standards developments.
- **Modeling R&D.** Modeling R&D and development of data analytics will help to leverage the data platform development to better inform decision-making.

Logistics and Implementation. Logistical barriers to institutional collaboration between entities in the water and energy sectors should be addressed.

- **Institutional Collaboration**. Targeted institutional collaboration between water and energy entities (utility-to-utility, agency-to-agency) can bring sustainability benefits.

- **Expand Certification Programs.** Conservation certification programs can be expanded to include calculation of cross-sector savings, and also verification and evaluation after project completion.
- **Explore the Utility Business Case.** Developing understanding of utility business cases for water-energy projects can help support conservation efforts. Building understanding of the short and the long term benefits to the water and energy sectors of investment decisions can help to inform sector investments and also identify potential gaps in investment that government programs can address.

The figure below outlines the framework developed and has been used throughout this report to highlight different action areas (large colored boxes). It illustrates how each of the eight next steps (small boxes) supports the four sub-goals (black boxes) that improve the ability of stakeholders to advance the overall system goal.



5.2. Stakeholders in the Water-energy Nexus

A wide range of stakeholders in the water-energy nexus exist across academia, government, industry, and non-governmental intervenor and other groups. Each of these stakeholders fulfills different roles in development within the nexus and represent different groups of consumers and their concerns.

Responsibility for energy and water management and planning is distributed among various agencies across a variety of agencies at the federal and state level. State and Federal agencies can promote the participation of stakeholders across in discussions on water management and potential establishment of unified water markets. Within the Federal government responsibility for water including quality, conservation, infrastructure, collaboration, and research include a diverse group including Environmental Protection Agency (EPA), Department of the Interior (DOI), Department of Commerce (DOC), Federal Energy Regulatory Commission (FERC), and Department of Agriculture (USDA), and various others.[41] Regulatory bodies for energy that are responsible for a range of different activities including generation, transmission, distribution, environment, and standards include the Department of Energy (DOE), Federal Energy Regulatory Commission (FERC), North American Electric Reliability Corporation (NERC), Environmental Protection Agency (EPA), National Institute of Standards and Technology (NIST), and various others. Additionally, interagency collaborations exist across an even wider range of agencies.

There is even more diversity at the state level. For example, in California regulatory bodies relevant to the water-energy nexus include the California Public Utility Commission (CPUC), State Water Resource Control Board (SWRCB), California Energy Commission (CEC), and the California Air Resources Board (CARB). These agencies are concerned with the development, planning, and promoting compliance with standards and regulations. Moving forward, taking into account the sensitivities of the coupled water-energy system in these efforts can streamline the development and implementation of effective actions towards addressing identified issues.

In addition, industry includes the utilities, non-profits, consumer groups, technology vendors, consultants, and private companies. These entities also represent a diversity of interests, concerns, and potential contributions. Collaboration with utilities that provide water and energy services to customers is especially important for ensuring that customer demand is met as the coupled water-energy system evolves. Companies that operate in multiple states have to consider a wide range of regulations, standards and consumers.

Finally, research and educational institutions can play many important roles in data development, modeling, innovation, and collaboration, with the primary role of the universities grounded in conducting research and providing education regarding the coupled water-energy system. University researchers can help illuminate understanding of the behavior of the coupled water-energy system. Educating students to interpret and analyze data can build long term analytic capability in the institutions where those students continue their work after they graduate. Laboratory and university investigators can also pursue research leading to next generation technologies to address needs across the water-energy nexus.

Stakeholder engagement across this diverse group is an important step in improving systems understanding, and data management, and collaboration.

5.3. Additional Considerations

41 Congressional Research Service. “Selected Federal Water Activities: Agencies, Authorities, and Congressional Committees.” R42653. August 2012. http://aquadoc.typepad.com/files/crs-federal-water-activities-agencies-authorities-and-congressional-committees.pdf

Including agricultural water users in dialogue and decisions about changes in water management and potential water-energy efficiency benefits can open up opportunities for better managing agricultural water use, similar to urban efficiency improvements. Continuing regional coordination development can help planning efforts for utilities.