THE WATER-ENERGY NEXUS: TRANSATLANTIC SOLUTIONS TO A GLOBAL CHALLENGE

USING THE INTERRELATION OF WATER & ENERGY TO INCREASE ELECTRIC GRID STABILITY

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Conference: University Association for Contemporary European Studies (UACES)
Edition: 44th Annual UACES Conference

Version: Final Paper
Word count: 3704 (4292)

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[1] Aster, 2012.

THE CHALLENGE

Water and energy are critical to economies on either side of the Atlantic. The significant historical investments in water and energy infrastructures have contributed to the industrialization and economic success of western nations. Europe, North America as well as the rest of the world are heavily dependent on continued supply of water and energy for economic competitiveness, industrial production and societal wellbeing.

Throughout the world, water production and distribution costs are rising. Water and energy are scarce in many regions of the world. Lower water levels coupled with growing populations drive ever increasing pumping costs as providers struggle to meet consumer demand. Seasonal operations, lack of benchmarking data and the lack of available capital in the municipal sector result in functional, yet sub-optimal, networks.

In parallel, the finite nature of fossil fuels, the growing concern over nuclear generation in some parts of the world and the increasing cost of carbon emissions are resulting in higher energy costs worldwide. Also, as Europe, the United States and the rest of the world continue to transition from a fossil fuel and nuclear based energy system to non-conventional power supply and intermittent renewable generation, grid operators will be forced to redefine how they procure energy and how they address load management in order to continue to provide safe, reliable and available power.

Continued population growth and economic development will further amplify water and energy consumption. While globally, demand for water and energy can be met, regional scarcity is exacerbated. The regional availability of water and energy depends on seasonal as well as daily consumption patterns and both resources are heavily interdependent: Energy production requires considerable amounts of water and water infrastructure depends on substantial input of energy. The alignment of water and energy production peaks are not understood and very little consideration is given to time of use on the demand side. The impact of these patterns are not fully appreciated or addressed to the extent that they can benefit both resources. Therefore, governments, business and civil society in Europe and North America suggest thinking in terms of the ‘water-energy nexus’.

THE PUZZLE

If this water-energy nexus yields enough potential to increase electric grid stability, why do some countries opt to make use of the interrelation between water and energy infrastructures while other countries opt for alternative policy solutions?

HYPOTHESES

The challenge introduced above poses the important question whether the water-energy nexus indeed provides for enough potential to increase electric grid stability. To answer this question, the concept of ‘interrelation’ between the water and energy infrastructure needs to be defined. Subsequently this interrelation needs to be quantified. Therefore, this paper proposes the following two hypotheses.

HYPOTHESIS 1

The interrelation between water and energy infrastructures yields *enough* potential to increase electric grid stability.

HYPOTHESIS 0

The interrelation between water and energy infrastructures yields *too little* potential to increase electric grid stability.

RESEARCH DESIGN

To test these two hypotheses, the paper proposes a most similar research design with two variables that will be analyzed for two case studies:

DEPENDENT VARIABLE

Electric grid stability

INDEPENDENT VARIABLE:

Interrelation

CASE STUDIES:

California (US)
Germany (EU)

METHODOLOGY

To operationalize the independent variable, the paper proposes three indicators. These indicators are water system efficiency, water conservation and water storage. Each indicator boasts a number of potential solutions that could provide for energy efficiencies by aligning water and energy production peaks.

WATER SYSTEM EFFICIENCY

- Pumping optimization;
- Variable flow controls;
- Pressure management;
- Water leak-loss detection and remediation;
- Distributed generation opportunities such as in-conduit hydro, distributed solar and particularly biogas generation and storage.

WATER CONSERVATION

- Integrated water and energy conservation programs leading to significant demand reduction or shift consumption to off-peak hours taking advantage of direct and embedded energy savings (direct: cooling & heating of water; embedded: pumping and treatment).

WATER STORAGE

- Economically viable opportunities to add incremental water storage tanks and reservoirs throughout water distribution systems;
- Strategic placement of such systems to contribute to demand reductions for up to 8 hours.

This paper combines a number of primary and secondary sources to address the correlation between water and energy infrastructures and potentially establishes causation between this interrelation and the potential to increase electric grid stability.

At present the research has not yet taken a more specific angle on specific water infrastructure operators. The next step would be to collect data from water infrastructure operators active in California and Germany. This data can provide invaluable insight into the water-energy nexus and help establish whether the interrelation between the water and energy infrastructures yields enough potential to increase electric grid stability.

CALIFORNIA AND GERMANY: TRANSATLANTIC INNOVATORS

Both California and Germany have begun to address the water-energy nexus, but three reasons make them ideal case studies for the purposes of this analysis:

1. Both California and Germany are significantly reducing their nuclear energy generation capacity.
2. In terms of GDP, they have the strongest economies in their respective regions.[2]
3. California and Germany implement a number of innovative reforms that may or may not prove successful. These processes will provide invaluable insight for other countries that seek to reform their water and energy systems.

In the wake of the Fukushima disaster in 2011, Germany shut down 8 of 17 nuclear power plants and will phase out the remaining 9 nuclear plants by 2022. Germany thus has to replace the combined capacity of 160.9 GW[3] with alternative sources of energy or reduced consumption. Statistics show that the nuclear plants already shut down account for 47 GW or roughly 30% of Germany's installed nuclear energy capacity or 7% of Germany's entire energy mix.[4] To replace the energy, Germany's immediate response was to increase renewable energy output and reduce energy exports. While energy exports rebounded after a short period of adaptation, renewable energy provision remained high. Renewable energy accounted for 117.5 GW in 2010 and increased to 155 GW in 2012.[5] This represents an increase of 37.5 GW or roughly 33% of renewable energy capacity in two years. Alternative energy sources and energy efficiency helped shoulder the remaining 9 GW energy shortage. Despite fears over energy security and blackout, Germany did not experience substantial difficulty.

The German government has an ambitious plan to increase the share of renewable energies. "By 2020 renewables are to have a share of at least 35% in gross electricity consumption, a 50% share by 2030, 65% by 2040 and 80% by 2050."[6] Energy efficiency is key to accomplishing these goals, yet the International Energy Agency (IEA) cautions that "two thirds of the economic potential for energy efficiency is set to remain untapped in 2035." The IEA points out market barriers as an important hindrance specifically highlighting the "pervasive nature of fossil-fuel subsidies, which incentivize wasteful consumption at a cost of $544 billion (€402 billion) in 2012."[7]

In its 2003 Energy Action Plan[8], California established a loading order to address new load requirements which prioritizes efficiency and conservation, followed by renewable generation and load management in the form of load-shifting and demand response. Collectively, these are known as "preferred resources". Furthermore, California's Renewable Portfolio Standard established through the state's legislature is targeting 33% of total

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[2] World Bank, 2012; US Government Revenue, 2013.

[3] Lechtenböhmer et al., 2012.

[4] Lechtenböhmer et al., 2012, p. 235.

[5] Lechtenböhmer et al.,2012; Stegen et al., 2013.

[6] The German energy concept, 2010.

[7] International Energy Agency, 2013.

[8] State of California, Energy Action Plan 2003.

procurement to be renewable energy by 2020[9]. In June of 2013, a decision was taken to permanently close the San Onofre Nuclear Generating Station (SONGS). The 2.2 GW plant represented 43% of installed nuclear energy capacity in California.[10] As a result, the local utility – Southern California Edison (SCE) – is looking to address the local capacity requirements through a public procurement process. Of particular concern is addressing demand peaks in an already congested region. In addition to proposed new generation, SCE has proposed to initiate a "Living Pilot" which would target preferred resources (e.g. energy efficiency, demand response, distributed generation, interconnection, and storage) to meet local capacity. This must however be done in a fashion that ensures grid stability and resiliency.

Germany has shut down 30% and California 43% of installed nuclear energy capacity. Instead they champion energy efficiency, renewable energy sources and other alternatives. The large scale decommissioning of nuclear generation plants and the increased adoption of distributed and intermittent renewable energy production results in the need to address local capacity requirements which can act as voltage support and contribute to maintaining grid stability.

Thus, California and Germany are facing the same challenge. How can they replace nuclear power in their energy mix while ensuring local grid reliability?

THE WATER-ENERGY NEXUS: AN OPPORTUNITY

The interrelation of water and energy offers the opportunity to increase electric grid stability after nuclear decommissioning in California and Germany. This can address demand peaks in congested regions and manage the growing intermittent load due to widespread distributed generation. Governments, business and civil society on either side of the Atlantic are proposing solutions in energy efficiency, demand response, distributed generation, interconnection, and storage. Best practices in California and Germany, traditional innovators in their respective regions, can be implemented throughout Europe and the United States. Economic competitiveness is key and special attention must be paid to achieving cost-effective grid stability and resilience during the all-encompassing transition from nuclear energy to alternative energy sources. Exchange of best practices and a common strategic approach to the water-energy nexus will help re-establish much needed trust in transatlantic relations.

PATH DEPENDENCIES AND INFRASTRUCTURE CONSTRAINTS

Significant historical investments in water and energy infrastructures have contributed to the economic success of western nations. These infrastructures however are ageing and must be maintained in order to continue to serve their functions to society.

A 2011 Ministry of the Environment report on water infrastructure specified that Germany spent €4.5 billion ($6.1 billion) on public wastewater disposal and invested €2 billion ($2.7 billion) on public water supply. Wastewater treatment consumes around 0.5 GW of installed capacity or 4,400 GWh per year and thermal power plants account for the largest share of water consumption in Germany with 10.4% or 19.5 billion m^3 of water per year.[11]

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[9] State of California, Senate Bill No. 2, 2011.

[10] US Energy Information Administration, 2010.

[11] Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), 2011.

In its fifth report to congress published earlier this year, the United States Environmental Protection Agency estimated that the United States will require $384 billion USD (€284 billion) of capital improvements to the United States water infrastructure. In California alone, $44.5 billion (€32.8 billion) in estimated costs are broken down as follows: $26.7 billion (€19.7 billion) for transmission and distribution, $2.5 billion (€1.85 billion) for source improvements, $8.4 billion (€6.2 billion) for treatment, $6 billion (€4.4 billion) for storage and $325 million (€240 million) for various other improvements.[12]

Necessary investments in the electricity grid are similarly high, however estimates for the industry and energy infrastructure vary as they are borne by the respective companies and utilities. For example, wind energy is primarily produced in northern Germany whereas energy consumption is concentrated in western and southern Germany. A number of nuclear power plants that provided the flat load in these industrious areas have now been decommissioned. The electric grid needs upgrading focusing on north to south connections or alternative solutions such as localized renewables, energy storage and demand response.[13]

Germany's energy policy is characterized by the Renewable Energy Sources Act (EEG) of 2000, Germany's energy transition (*Energiewende*) of 2010 and the return to the legal obligation to shut down all nuclear power plants in the wake of the Fukushima nuclear disaster.[14]
The German energy market is characterized by an oligopoly of four big utilities. The EEG, the *Energiewende* and the decision to opt out of nuclear energy opened up the market to more energy providers and might lead to cheaper energy prices in the long run.[15] In the initial stages of this transition, energy prices increase however. New and emerging renewable energy providers, such as wind, solar, photovoltaic, biomass and hydropower are subsidized with feed in tariffs (FITs). Economies of scale have only partially materialized. While onshore wind power and hydropower realize competitive prices, offshore wind power, solar, photovoltaic and biomass still require FITs.

Germany seeks to finance the necessary investments in energy infrastructure and renewable energy sources via the EEG-allocation collecting a fixed amount per KWh delivered to end-users. The EEG-allocation has risen sharply from €0.02/KWh ($0.03/KWh) when it was first introduced in 2010 to €0.06/KWh ($0.08/KWh) in 2014.[16] The main reason is a rapidly growing renewable sector and an exemption for energy intensive industries operating in globally competitive markets. Companies profiting from the exemption increased from 297 in 2005 to 1550 in 2013.[17] The German government is now preoccupied with the costs of the EEG-allocation rather than focusing on economic and competitive benefits of fostering

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[12] US Environmental Protection Agency, 2013.

[13] Breuer et al., 2012.

[14] For a detailed discussion of German legislation please refer to: Lechtenböhmer et al.,2012; Stegen et al., 2013; Overview of energy laws and regulations, German Federal Ministry of Economy. Main laws regulating the *Energiewende*: Renewable Energy Sources Act; Renewable Energy Heat Act; Grid Expansion Acceleration Act; and Energy Economy Law.

[15] Nestle, 2011; German Advisory Council on the Environment, 2011.

[16] EEG-KWK Umlage.

[17] Klima-Allianz, 2013.

renewable energies.[18]

Meanwhile, we are transforming how we use these infrastructures. On the demand side, per capita consumption of water and energy is decreasing or remaining at status quo[19], while the usage profiles are adapting as technology and society evolves to increasingly rely on technologies such as air conditioning or electric mobility. On the supply side, the number of distributed producers is increasing and the traditional flat base loads provided by large coal and nuclear plants is being replaced by variable load. As a result, grid operations are becoming increasingly complex and society must find innovative and cost effective ways of ensuring safe and reliable load to end-use customers.[20]

The infrastructure is already in place and long-term investments have been made. We continue to invest billions of dollars every year to maintain these infrastructures without truly understanding the value that could result from integrating the management of both resources. Hence, business and policy communities on either side of the Atlantic face important path dependencies and must adapt the existing infrastructure to changing use.

As the United States and Europe transition to a clean energy economy, they face increased challenges to maintain voltage support to ensure grid stability. Strategies to adapt the electric grid to a more flexible supply side have to include load management such as 'demand response' through a smart grid allowing IT solutions in managing load shifting of energy and water consumption. Load shifting and storage should take place in an interconnected manner allowing for back-up capacity plants[21] but also energy storage across sectors. Energy storage should rely on existing infrastructure to allow cost-effectiveness and should include short and long-term water storage as well as chemical storage in the form of Power to Gas (PtG).[22] These innovative and economically attractive solutions alleviate the pressure on grid bottlenecks and can help handle surplus generation of renewable energy.

WATER AS A SOLUTION TO ENERGY CHALLENGES

Both Europe and the United States have invested countless resources over several centuries to establish the existing infrastructures required to collect, treat and distribute water and wastewater. This water infrastructure is heavily dependent on the energy required to pump water, treat it and distribute it. In California, water distribution and treatment is estimated to consume 19% of the state's electricity, 30% of its natural gas and 88 billion gallons of diesel fuel each year.[23] This energy is known as the embedded energy in water systems. Water may require different amounts of energy to produce in function of various drivers including source such as ground, surface, and desalinization, but also quality, location, time of year and environmental regulation. The amount of energy required to move a certain amount of

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[18] Altmaier, 2013.

[19] Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), 2011; Energy Realities, 2013; California Energy Commission, 2007.

[20] Ethik-Kommission - Sichere Energieversorgung, 2011.

[21] "energy plants running on conventional fuels that are needed when, for example, the wind does not blow or the sun does not shine (see Friedman, 2011; Winkler and Altman, 2012)." (Stegen et al., 2013, p. 1487).

[22] Breuer et al., 2012, p.1.

[23] California Energy Commission, 2005.

water is known as its energy intensity. The energy intensity of water systems directly impacts the real-time grid operator's requirements to provide reliable power to water agencies and cities. The ability to reduce this energy intensity, temporarily and shift it to a different time would be of enormous value to grid operators in order to control voltage and ensure grid stability.

Furthermore, wastewater treatment facilities can be used to generate energy through the bio-methane produced from Anaerobic Digestion in the treatment process. Adding additional organic waste such as fats, oils and grease can increase the amount of methane generated and therefore produce additional power. Methane can be stored and the facilities can run on its own generation for extended periods of time. This essentially means that wastewater treatment facilities can be used as renewable peak generation sites.[24]

CONCLUSION: THE ADDED VALUE OF NEXUS THINKING

Traditionally water and energy have been managed separately and are often regulated by completely different entities. No consideration is given to the alignment of water and energy production and demand peaks. Therefore significant opportunity remains to be explored on the integrated management of both resources.

Water distribution and treatment systems are an ideal candidate to manage grid stability.

- They are large energy consumers
- They are essential to society and region-specific
- Most of the infrastructure is already available
- They are centrally managed by water agencies and local governments
- They manage variable demand of a resource for a large number of customers in different market segments

Electric system operators, transmission planners, and procurement entities should leverage the ability and availability of preferred resources in water systems to perform where and when they are needed. Preferred Resources to meet local reliability, while ensuring grid stability and resiliency include:

1. Energy and demand savings
2. On-peak to off-peak demand shifting
3. Distributed renewable generation
4. Demand response events

A resource assessment must be carried out to calculate the energy intensity of regional water systems and evaluate the potential for water system conservation, efficiency improvements, operational improvements and renewable generation. Based primarily on the outcome of the resource assessment, high potential opportunities can be developed leveraging the water-energy nexus to mitigate the capacity loss due to nuclear decommissioning in California and Germany. The implementation of such a strategy would be 3 tiered:

(1) **System Efficiency:** Both short and long-term energy optimization of components and systems in water infrastructure facilities can replace considerable amounts of on-peak power which no longer have to be produced at substations impacted by power plant closures. Energy efficiency components could include pump optimization, variable flow controls, pressure management, water leak-loss detection and remediation. Identifying and keeping track of energy and demand reduction opportunities by each utility

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[24] California Association of Sanitation Agencies, 2013.

substation is key to prioritizing investments. This approach should also look at distributed generation opportunities such as in-conduit hydro, distributed solar and particularly biogas generation and storage.

(2) **Water Conservation**: Joint programs should be developed between electric and water utilities to take advantage of “Embedded Energy” savings in water conservation. Water conservation can reduce both direct energy use at the place of consumption (such as hot-water heating) and embedded energy to treat and pump water to the site. Integrated water and energy conservation programs can lead to significant demand reduction or shift consumption to off-peak hours.

(3) **Water Storage**: There are significant amounts of economically viable opportunities to add incremental water storage tanks and reservoirs throughout water distribution systems. The strategic placement of such systems can contribute to demand reductions for up to 8 hours. Energy costs for water utilities are about 35% of their costs and are often the second biggest expense after labor costs. Water and wastewater utilities however often neglect energy efficiency resulting in increased investment requirements for power plants as well as transmission and distribution system assets. Water and wastewater customers must incorporate energy efficiency into existing and planned water systems infrastructure systems.

Legislators on either side of the Atlantic began their work on the water-energy nexus. The German government tasked the Federal Ministry for Environment, Nature, Conservation and Nuclear Safety (BMU) and the Federal Ministry for Economic Cooperation and Development (BMZ) to work on the water-energy nexus.[25] The Californian government allocated the topic to the Energy Commission highlighting energy and water efficiency.[26] The International Energy Agency’s World Energy Outlook 2012 examines the water-energy nexus in a separate chapter and in 2013 energy efficiency is proposed as solution.[27]

This paper has offered a cross-sector approach to the water-energy nexus. Instead of new large scale investments, existing water and energy infrastructures should be leveraged to relieve pressure on the energy sector and manage energy load. The Integration of water and energy infrastructures promises to yield a viable and cost-effective solution to water and energy management in California and Germany.

CONTINUED RESEARCH AGENDA

This paper highlighted the interrelation between water and energy infrastructures as potential to increase electric grid stability. The paper opted for a most-similar research design to validate this hypothesis.

The next step needs to address the research puzzle itself. Why do some countries opt to make use of the interrelation between water and energy infrastructures while other countries opt for alternative policy solutions?

This paper thus prepares the ground for further research in the area of comparative politics with regard to the water-energy nexus. An interesting research agenda could include a most-

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[25] The German Federal Government, 2013; The Guardian, 2013.

[26] California Energy Commission, 2013; National Council of State Legislators, 2009.

[27] International Energy Agency, 2013.

different research design with California and Germany on the one hand, and two cases that opt for alternative policy solutions to increase electric grid stability on the other. Such research could answer the important puzzle why some countries opt to make use of the interrelation between water and energy infrastructures while other countries opt for alternative policy solutions.

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