KAPSARC Energy Workshop Series

KAPSARC
مركز الملك عبدالله للدراسات والبحوث البترولية
King Abdullah Petroleum Studies and Research Center

# Energy for Water

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## About KAPSARC

The King Abdullah Petroleum Studies and Research Center (KAPSARC) is an independent, non-profit research institution dedicated to researching energy economics, policy, technology, and the environment across all types of energy. KAPSARC's mandate is to advance the understanding of energy challenges and opportunities facing the world today and tomorrow, through unbiased, independent, and high-caliber research for the benefit of society. KAPSARC is located in Riyadh, Saudi Arabia.

## Legal notice

## Summary for policymakers

Most policy responses to increasing water scarcity have come from the supply side, namely via increases in advanced water treatment as well as extraction from deep, nonrenewable underground aquifers. These practices consume significant energy resources. Energy used to extract surface water is roughly 0.027 $kWh/m^3$, while groundwater extraction and desalination can require up to 1.2 $kWh/m^3$ and 48 $kWh/m^3$ respectively.

Policies that reduce water demand provide opportunities to help maintain the sustainability of water resources and decrease energy use. Examples of policies that reduce water demand include increasing water and energy prices to reflect marginal and opportunity costs, discouraging water intensive industries including some segments of agriculture, and increasing public awareness about the importance of conservation.

Advanced water treatment is necessary in some water scarce countries. When employing advanced treatment, the choice of technologies adopted can have a profound effect on energy use. For example, thermal desalination technologies (11-48 $kWh/m^3$) are the most energy intensive, followed by membrane technologies (4-7 $kWh/m^3$) and wastewater treatment technologies (0.3-1.5 $kWh/m^3$). As a result, in water scarce countries, policies that encourage the reuse of wastewater and the adoption of membrane technologies may help decrease energy use.

There may be benefits in considering water pricing, agriculture, and water treatment policies within a wider social policy framework. This is because policy reforms would likely have short-term negative effects on some sectors of society, particularly in emerging economies.

There is value in governments engaging both private and public stakeholders to determine the best way forward. Engaging multiple stakeholders will not only ensure the effects of policy reforms on different actors are considered, but may also increase the likelihood that any policy reforms agreed upon will be accepted and ultimately adopted by all.

## Background to the workshop

In September 2014, KAPSARC hosted a workshop in Paris to explore the "energy for water" component of the water-energy nexus. Energy for water was chosen because it has received less attention in discussions on water and energy, which to date have focused largely on how water is required in the production of different energy resources.

Water and energy form a nexus with agriculture that requires a more integrated analysis. Large quantities of water are used to produce hydroelectricity, cool power plants, stimulate oil and gas reservoirs, and refine petroleum products. Similarly, energy is a critical input for the extraction, treatment, and transportation of water, much of which is used by the agriculture sector. Unsound management of either resource can have an impact on the cost, availability, and sustainability of the other.

The objectives of the workshop were to:

- Explore the similarities and differences in countries with respect to managing the energy they expend to provide water
- Describe the energy implications of using different technologies for extraction, treatment, and transportation of water
- Discuss the controllable and uncontrollable factors affecting the potential for countries to make improvements in their energy use for water

Participants explored diverse country case studies on how energy is used to meet water demand.

Specific questions addressed included:

- Why do countries adopt different technologies for advanced water treatment and irrigation systems?
- What role do energy and water prices, water quality (including pollution and salinity levels) and public finances play in technology choices?
- What political and geographical factors constrain the ability of countries to reduce energy and water use? For example, in countries facing severe water scarcity, where water demand can only be met through desalination or accessing deep underground aquifers, even efficient water production and consumption may result in significant energy usage.
- Can reducing the level of water demand or adopting more efficient water extraction and treatment technologies reduce energy costs effectively?

Addressing these questions contributes to a rounded assessment of the challenges and opportunities that face countries relying on energy to overcome their water scarcity.

## Managing water scarcity: Supply vs demand

Increasing populations, climate change and economic development are straining water resources in many parts of the world. To date, most policy responses to increasing water scarcity have come from the supply side, namely via increases in advanced water treatment practices (desalination and wastewater treatment) as well as extraction from deep, nonrenewable underground aquifers. In the last 10 years, online desalination capacity has increased from 0.72 $km^3$ to 13.73 $km^3$ globally (Desal Database, 2014).

> **"After a certain level of consumption water ceases to be a human right."**

While supply side responses to water scarcity may be necessary in the short run, they impose significant financial and energy costs on economies. For example, to combat water scarcity in Australia, governments increased infrastructure spending from

AU$2.4 billion to over AU$14 billion between 2005 and 2009. This infrastructure expansion has resulted in a 250% increase in energy expenditure for water provision (Kenway and Lant, 2012). As a result, it is important to consider how policies that reduce demand for water can decrease financial and energy costs, and improve the long-term sustainability of water resources.

> **"We are trying to allocate resources in a market that is full of distortions."**

In cities, the marginal benefits of reducing water consumption present a significant opportunity. There are two reasons for this. First, because most water for municipal use must be treated prior to consumption, transported before and after consumption, and then treated again prior to being reintroduced into the water system, municipal water provision requires large investments in infrastructure and energy. Reducing demand would decrease the need to invest in this infrastructure, and would reduce energy usage.

Second, municipal water is used by households and industry for a wide variety of energy intensive activities. For example, Figure 1 shows that in the United States roughly 12.6% of total primary energy consumption is directly related to water use, like heating water in the residential sector or water pumping in the industrial sector (Sanders and Webber, 2012). Similarly, in Australia roughly 86% of the energy demand related to the urban water

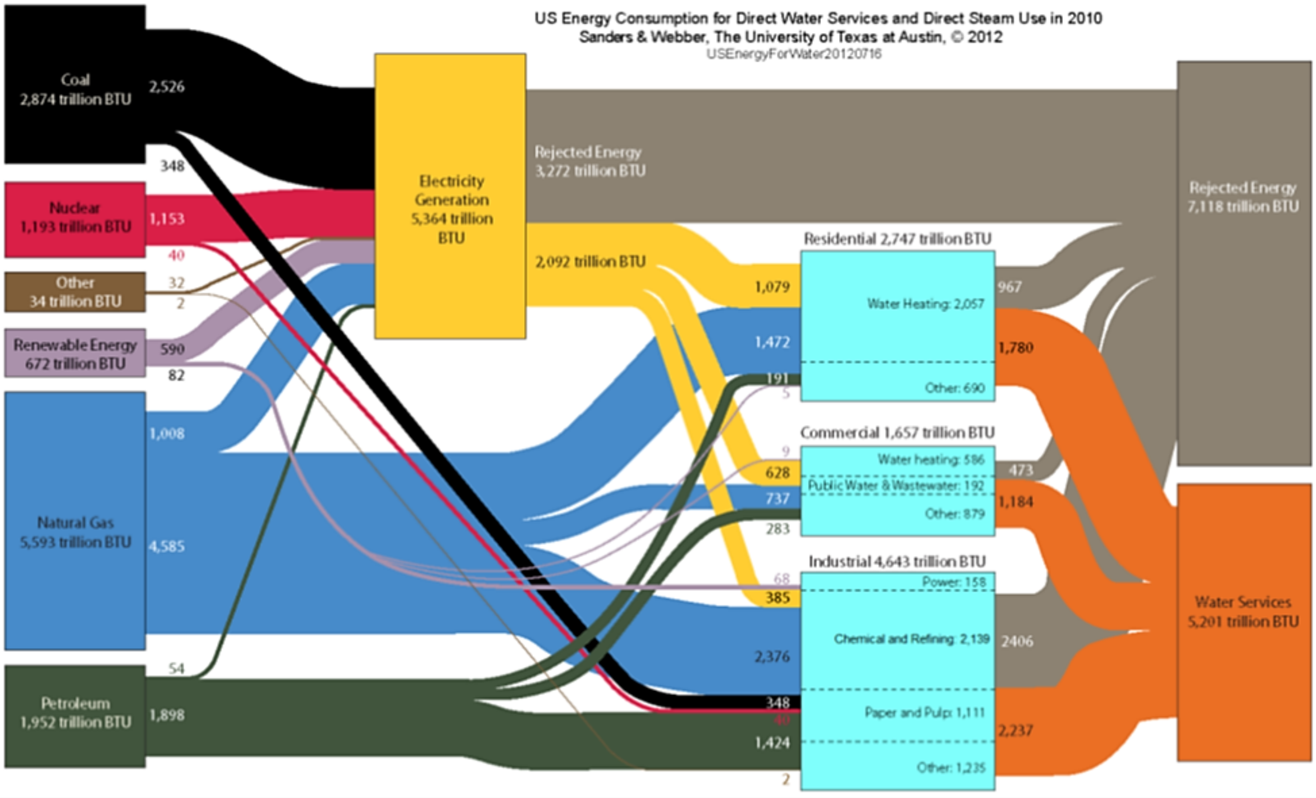


**Figure 1:** US energy consumption for direct water services and direct steam use in 2010. Source: Sanders and Webber, 2012

cycle is a function of how water is used. Heating water in the residential sector and heating, cooling and pumping water in the industrial sector account for 31% and 32% of total energy demand respectively (Kenway et al., 2011). Because of this, targeting water reductions in areas where energy use is high could lead to significant energy savings throughout the system.

An equally important component of water and energy management is improving existing water systems, including reducing leakages and improving the efficiency of pumps for water extraction and transportation. While often capital intensive, updating existing infrastructure can reduce energy use and improve the long term sustainability of water systems.

In addition to reducing consumption and improving infrastructure, there are less obvious controllable factors that have led to rises in energy use for water provision. For example, industrial and agricultural activities may have polluted surface and groundwater, which has necessitated more costly, energy intensive water treatment processes. Reducing pollution of water sources that are relied on for consumption can decrease energy and water treatment costs.

## Advanced water treatment technologies

Adoption of advanced water treatment is driven by both water scarcity and environmental concerns. Specifically, countries may choose to desalinate water to supplement surface and groundwater supplies, while environmental legislation is increasingly mandating that wastewater be treated with advanced technologies prior to discharge.

Supply constraints and regulations are leading to more advanced water treatment, but the choice of technologies adopted is a function of economics and geographical factors. For example, the Gulf Cooperation Council (GCC) countries have historically adopted energy intensive thermal desalination technologies—such as multi-stage flash (MSF) and multi-effect distillation (MED). The reasons for this are threefold:

– the salinity of seawater in the region is very high at roughly 41-45 g/l, compared to the global average of 34.5 g/l (Bashitialshaaer et al., 2011), and thermal technologies are often considered more reliable for producing large quantities of water from highly saline sources

– thermal desalination can use waste heat from cogeneration power plants, thus allowing water and energy needs to be met simultaneously

– thermal technologies, which are more energy intensive but less capital and labor intensive, produce water more cheaply than membrane technologies—like reverse osmosis—when energy prices are very low

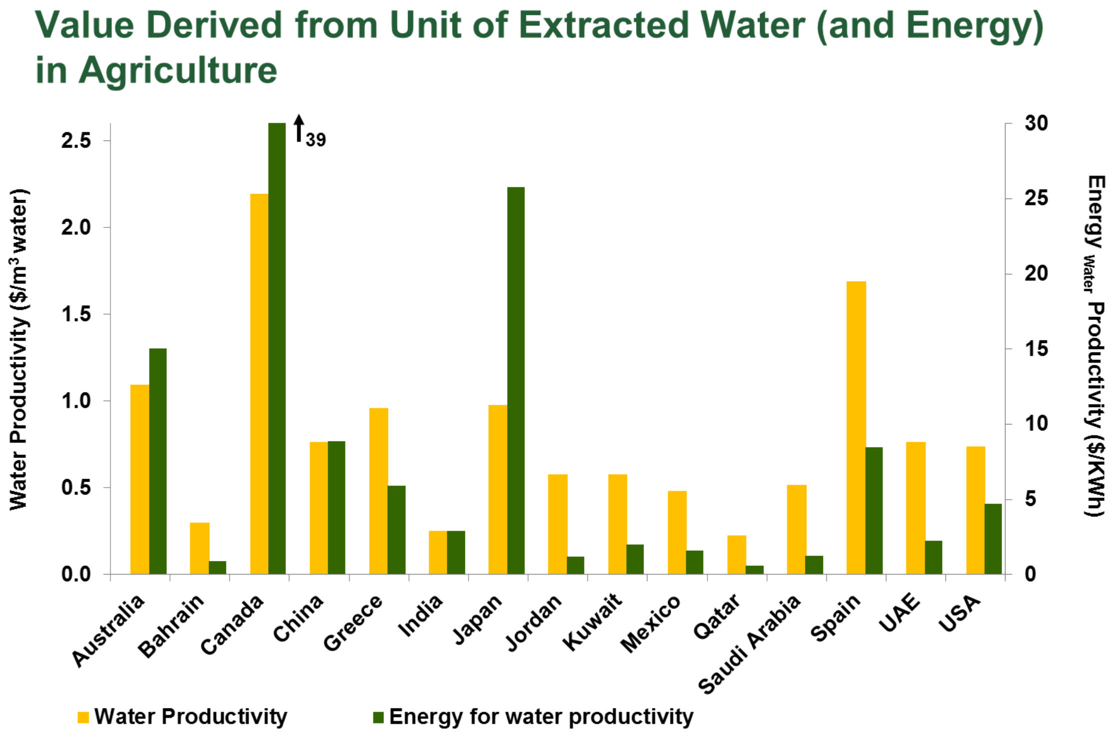
The adoption of thermal technologies has resulted in the GCC region having the highest energy intensities for water production in the world.

> **“Improving water productivity is an opportunity for energy efficiency and environmental conservation.”**

By contrast, countries like Spain, the United States, India, China, Greece and Australia have almost exclusively adopted less energy intensive membrane technologies. This is because the costs of energy are so much higher, and energy represents a significant proportion of overall desalination costs. For example, on the Greek Island of Syros, the cost of desalinating water is between 1.2 €/m$^3$–1.6 €/m$^3$, with energy representing 45% of total production costs (Assimacopoulos, 2014). Whereas, in the GCC region, lower prices have resulted in energy representing as little as 25% of total production costs. The high proportion of desalination costs devoted to energy, even when using energy efficient membrane technologies, explains why energy prices play a large role in which technologies are adopted for desalination. One way GCC countries could encourage the adoption of energy efficient desalination technologies is by increasing the administered prices of energy, which are currently very low in the region. For example, in Saudi Arabia, the price of both natural gas and Arab light crude is roughly $0.75 per million btus (Matar et al., 2014). Raising prices, however, would increase the total cost of water, and could have a negative effect on consumers and the overall economy during the transition. It is important for policymakers to learn how water is used for production, and how it is consumed by households, to understand which stakeholders may be most affected by price increases.

> **“The next best water source is always more energy intensive than the best.”**

In addition to adopting more energy efficient desalination technologies, encouraging wastewater reuse offers potential for energy reductions in countries relying on advanced treatment. Treating wastewater for consumption is less energy intensive than desalinating seawater. In many countries, however, there is a stigma associated with using treated wastewater for human consumption and agricultural irrigation. Engaging stakeholders to change these attitudes is an important component of policy reform.



Compiled Sources; KAPSARC Analysis

**Figure 2:** Value derived from unit of extracted water (and energy) in agriculture. **Source:** KAPSARC Analysis

## Energy for water in agriculture

Globally, agriculture consumes roughly 70% of total water withdrawals. Therefore, reducing energy used for water withdrawals will inevitably include an agricultural dimension. As Figure 2 shows, there are significant differences in water and energy productivity (as measured by the ratio of GDP to non-rain water) among countries. For example, Bahrain must use roughly three times as much water, and 15 times as much energy to extract that water, as Australia uses to achieve the same GDP in agriculture.

> **"We need a paradigm shift on how we produce food."**

The differences between countries are due to a combination of controllable (choices of agricultural policies) and uncontrollable (water scarcity and lack of rain) factors. For example, in Canada 99.4% of the water required to produce wheat comes from rain. By contrast, in Saudi Arabia only 18% of the water used to produce wheat comes from rainfall (Waterstat database, 2014). Using extracted water to grow agricultural products in Saudi Arabia has made the country far less energy and water productive than Canada. It is, therefore, reasonable to question whether it is rational to grow certain crops in Saudi Arabia, and other water scarce countries, recognizing the burden this places on both water and energy resources. In fact, the Saudi Arabian government has understood the significant water and energy costs of producing wheat domestically and will be phasing out production by 2016. There is some debate as to whether water scarce countries should attempt to achieve food security through supporting domestic agriculture.

Figure 2 also shows that many of the least water and energy productive nations are also the poorest. This begs the question as to whether developing countries with constrained budgets *should* seek to improve water productivity, given that initiatives may be expensive and highly capital intensive. For example, Mekonnen et al. (2014) show that applying 1% more labor would lead to a 3% increase in Pakistan's wheat yields, and applying 1% more capital spending (including tractors, laser levelers, threshers and bullocks) would lead to a 0.4% increase in wheat yields. Neither of these increases require increasing water use.

Increasing capital and labor inputs will improve the productivity of water, but the decision by agriculturists as to whether to make these investments will be based on the relationship between the costs of the inputs and the relative prices of the agricultural outputs. Should their return on these investments be negative, they would be unlikely to proceed despite a positive impact on the sustainability of water resources.

## Policy considerations

Challenges for improving energy for water are both economic and institutional. Regarding economics, in many cities the price charged for both water and energy is less than the private and social costs. As a result, there is overconsumption of the resource and it is not always allocated in production to where the value added is highest. In addition, low prices often result in a funding gap. Low revenues result in underinvestment in infrastructure maintenance (including pipeline leakage) as well as underinvestment in effective governance. Institutionally, lack of coordination between different levels of government and the authorities governing water, energy, and agricultural resources can lead to sub-optimal policies.

Reforms are best considered within a wider social policy framework because they may have disproportionately negative effects on certain groups. Governments that engage with both private and public stakeholders not only ensure the effects of policy reforms on different stakeholders are considered, but may also increase the likelihood that resulting policy reforms will be adopted by all.

## About the workshop

The workshop, held In September 2014 with some 40 international experts, was conducted under the Chatham House rules of capturing discussion in a non-attribution basis. Participants included:

**Walid Abderrahman** – Executive Chairman, Miahona, Saudi Arabia

**Esam Al-Amer** – Advisor, National Water Company, Saudi Arabia

**Samer AlAshgar** – President, King Abdullah Petroleum Studies and Research Center (KAPSARC), Saudi Arabia

**Abdulrahman Al-Ibrahim** – Governor, Saline Water Conversion Corporation (SWCC), Saudi Arabia

**Mohammad Al-Rashed** – Executive Director, Water Research Center, Kuwait

**Thabit Al-Safadi** – Water Division Team Leader, Electricity & Cogeneration Regulatory Authority (ECRA), Saudi Arabia

**Bader Alsaif** – Assistant to Governor, SWCC, Saudi Arabia

**Hisham Akhonbay** – Collaboration Specialist, King Abdullah Petroleum Studies and Research Center, KAPSARC

**Olivier Appert** – Chief Executive, Institut Français du Pétrole (IFP) /IAC KAPSARC

**Dionysis Assimacopoulos** – Professor, National Technical University of Athens, Greece

**Asit Biswas** – Professor, Lee Kuan Yew School for Public Policy, Singapore

**Benjamin Court** – Manager, Schlumberger Energy Institute (SEI), France

**Mohamed Darwish** – Principal Investigator, Desalination and Water Security Program, Qatar Environment and Energy Research Institute (QEERI), Qatar

**Mohamed A. Dawoud** – Water Division Team Leader, Abu Dhabi Environmental Agency, United Arab Emirates

**Romain Debarre** – Managing Director, Schlumberger Business Consulting, France

**Kankana Dubey** – Research Associate, King Abdullah Petroleum Studies and Research Center (KAPSARC), Saudi Arabia

**Kate Eklin** – Climate Finance and Investment Team, Environment Directorate, OECD, France

**Berenice Garcia-Tellez** – Senior Research Analyst, King Abdullah Petroleum Studies and Research Center (KAPSARC), Saudi Arabia

**Alberto Garrido** – Professor, Polytechnic University of Madrid, Spain

**Bassam Hayek** – Senior Expert, Deutsche Gesellschaft fuer Internationale Zusammenarbeit (GIZ), Jordan

**David Hobbs** – Head of Research, King Abdullah Petroleum Studies and Research Center (KAPSARC), Saudi Arabia

**Nicholas Howarth** – Research Fellow, King Abdullah Petroleum Studies and Research Center, KAPSARC

**Holger Hoff** – Senior Research Fellow, Stockholm Environment Institute (SEI), Sweden

**Steven Kenway** – Research Group Leader, Water-Energy-Carbon, University of Queensland, Australia

**C.S. Kiang** – Chairman, Sustainable Development Technology Foundation/IAC KAPSARC

**Xavier Leflaive** – Principal Administrator, Environment Directorate, Organisation for Economic Co-operation and Development (OECD), France

**Rabi Mohtar** – Research Professor, Texas A&M University, United States

**Khalid Mously** – Engineering Consultant, Cooperate Planning -Saudi Aramco, Saudi Arabia

**Christopher Napoli** – Senior Research Associate, King Abdullah Petroleum Studies and Research Center (KAPSARC), Saudi Arabia

**Daniel Nolasco** – Director, Water Environment Federation, United States

**Anand Plappally** – Assistant Professor, Indian Institute of Technology Jodhpur, India.

**Claudia Ringler** – Deputy Division Director, International Food Policy Research Institute (IFPRI), United States.

**Diego Rodriguez** – Senior Economist, Water Unit, The World Bank, United States.

**Kelly Sanders** – Assistant Professor, University of Southern California, United States.

**Adnan Shihab-Eldin** – Director General, Kuwait Foundation for the Advancement of Sciences (KFAS) /IAC KAPSARC

**Daniel Sperling** – Professor, University of California, Davis, United States.

**Michael Van der Valk** – Scientific Secretary, UNESCO, International Hydrological Program, Netherlands.

**Chunmiao Zheng** – Chair Professor and Director, Peking University, China.

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# Notes

## About the team

**Kankana Dubey** is a Research Associate investigating patterns of energy consumption in the water supply chain. She holds a MS degree from the University of Stirling.

**Berenice Garcia-Tellez** is a Senior Research Analyst evaluating the energy use associated with embodied water in the global trade of goods. She holds a Master’s degree in environmental engineering from KAUST.

**Christopher Napoli** is a Senior Research Associate. His research focuses on natural resource economics and energy policy. He has a PhD from the University of Kent.

**Sa’d Shannak** is a Research Associate investigating water-energy nexus and energy and the environment. He holds a PhD in water management from the Texas A&M University

## About the Project

The project’s objective is to understand how and why the energy required to meet water demand differs between countries. To explore this question, energy used for the extraction, treatment, and transport of water is decomposed. The decomposition offers an empirical base through which to examine how energy is used in the water cycle in countries.

Building on this empirical base, the project explores the controllable and less controllable factors that lead to differences in energy use for water provision. Particular consideration is given to the effects of industrial structure, pollution, water scarcity and pricing strategies on energy and water use.

In line with KAPSARC’s overall objectives, the project seeks to provide insights into how current policies influence the energy used for water withdrawals, and where improvements might be made. By exploring case studies from around the globe, the project highlights how successful practices in water and energy management from one country might be transferred to others.

The workshop series provides a space for dialogue on key issues, feedback on KAPSARC's study program, and options for future research.

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