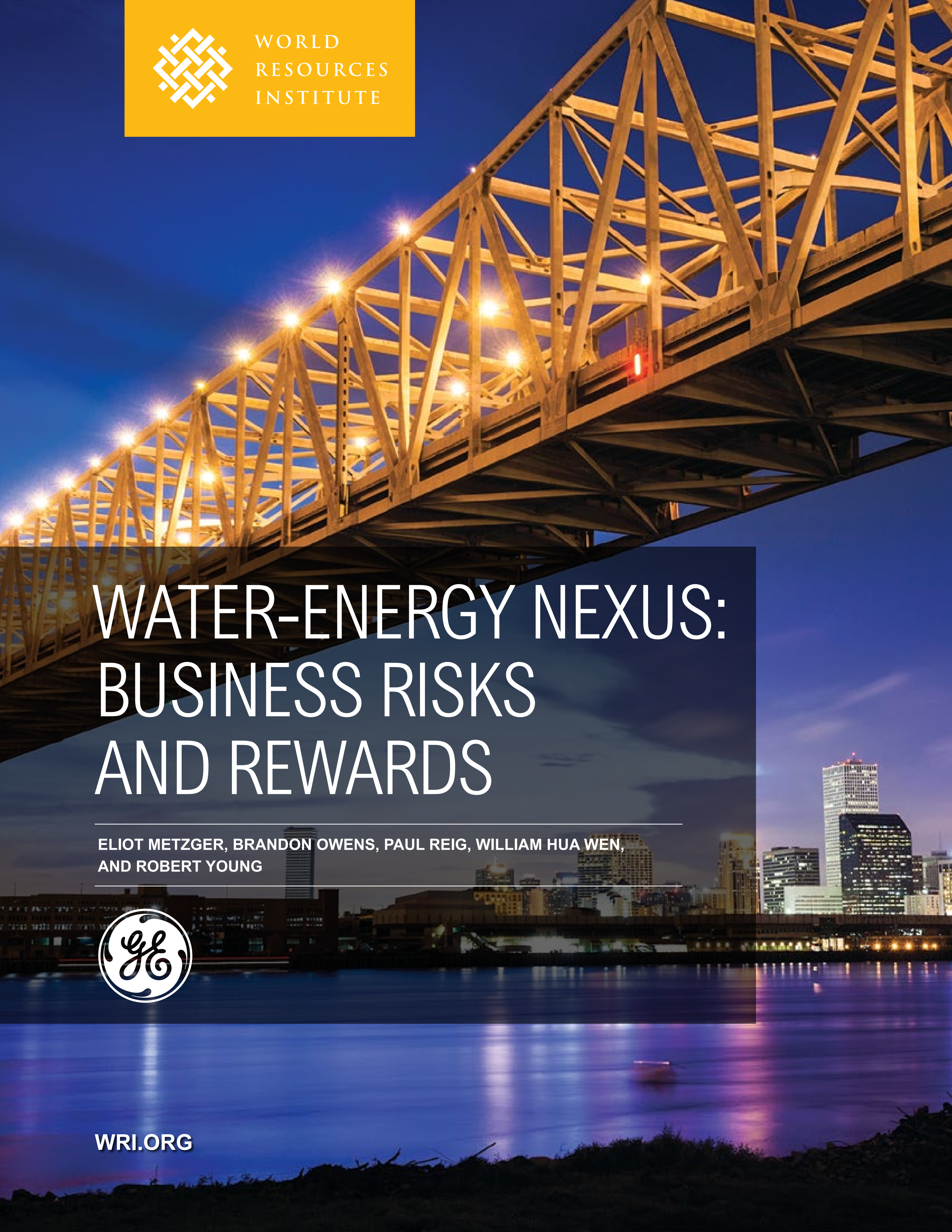

WORLD RESOURCES INSTITUTE

WATER-ENERGY NEXUS: BUSINESS RISKS AND REWARDS

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FIFA WORLD

PARTNER PERSPECTIVES

I joined WRI precisely because of issues like the water-energy nexus. It is a challenge that cuts across sectors, across geographies, and involves both public and private interests. It requires action from more than just one company.

This report shows that regions are already confronting water and energy challenges. It suggests multiple industries pay attention, and collaborate, to address the water risks for energy and energy risks for water. It outlines a list of opportunities, including an emphasis on shifting demand and scaling alternatives. It also points to opportunities where companies can address related social and economic priorities, such as gender equity.

I count water-energy challenges—and the resource consumption that drives them—among the top priorities for business over the next five years. I will be excited to see other companies join us and GE in sharing views of what is working (and what is not). There are real barriers, real tradeoffs to manage, but also real opportunity for those who find practical ways of meeting social, environmental, and economic needs. These are the thorny issues that will shape tomorrow's markets.

Kevin Moss
Global Director
World Resources Institute Business Center

As a 130-year-old technology company, GE has always believed in progress—in taking risks to improve our technology and build a brighter future for our customers and the world around us. From the invention of the first practical incandescent light bulb to building the world's first power plant, the GE tradition of life-changing innovations is unparalleled.

A decade ago, we decided that this meant redefining what it means to be green, so, in 2005 we launched Ecomagination. We adopted Ecomagination as our business strategy to provide cleaner technology solutions that improve resource efficiency and economics for our customers across the globe. We invested $15 billion to develop clean technologies and we recently committed to investing another $10 billion by 2020.

The resource challenges that we committed to help solve ten years ago persist, and new challenges have emerged that require new inspiration and even greater resolve. That's why we recently brought together a range of commercial partners to help us collaboratively create the innovation that will help solve the world's toughest resource challenges.

Within the next decade, one-third of the world's population will live in water-stressed regions. Water is also essential for agricultural and industrial production. Global industrial water demand alone is expected to increase by 250 percent by 2030.

The water-energy nexus is one area where we are focused on developing new innovations and exploring new business opportunities. This report explains why and offers ideas for how. We have always been hard at work innovating in our labs and factories, and on the ground with customers. Now, with our commercial partners, we are committed to work together to help build the solutions needed to power the world in the next decade and beyond. Join us as we work to help create a future that will enable the world, and everyone in it to thrive. The future has just begun, and the best is yet to come.

Debora Frodl
Global Executive Director
GE Ecomagination

EXECUTIVE SUMMARY

Water scarcity challenges industries around the world. Global population growth and economic development suggest a future of increased demand, competition, and cost for limited freshwater supplies. Scarcer water, in turn, creates new challenges for energy supply because coal, oil, gas, and electricity production can require massive amounts of freshwater. Yet many countries will need more energy for energy-intensive water treatment options, like seawater desalination, to meet their growing demand for water.

This interdependency is known as the "water-energy nexus" and is now a well-established concept, but the business risks and opportunities associated with it are still being understood. Companies in water- and energy-intensive industries (and their customers) have an increasing interest in evaluating and managing emerging risks. Specifically, industries face physical and financial risks when their supplies of freshwater and energy become more volatile (through supply disruption and price fluctuations) and costly (because of new regulations, competition, and infrastructure and operational costs). Importantly, there are also social risks and considerations, especially in countries where millions of people still lack access to improved water sources and electricity.

Companies can look to industries and regions now facing risks at the water-energy nexus for insights on the challenges coming to their own regions or value chains. This report looks at three regions where industries that face risks related to water and energy supply are finding emerging solutions to address their reliance on scarce resources:

- **In the Middle East and North Africa**, countries face extremely high water stress and are using oil and gas to power desalination plants to address the widening freshwater supply gap. One country is projected to use all of its current energy production for desalination by 2035.
- **In China**, where economic growth is increasing demand for electric power, nearly 60 percent of coal-fired power generation plants face high or extremely high water stress.
- **In the United States**, 60 percent of shale gas plays will face arid conditions or high or extremely high water stress by 2020.

Risks and opportunities in these regions are a wake-up call to other regions and those who rely on their products. They suggest a high-level checklist for companies operating at the water-energy nexus:

- **Acknowledge emerging risks to supplies of water and energy, but don't overlook solutions that address demand.** *Why try to squeeze more out of limited freshwater supplies when end-use efficiencies offer water-energy "win wins"?*
- **Take full advantage of water reuse and energy recovery.** *Why waste valuable water and energy resources when they can be put to use reducing costs and supply risks?*
- **Shift demand to alternative water options and clean energy resources.** *Why rely only on freshwater and fossil fuels in a world of increasing demand and competition for those sources?*
- **Create new partnerships and business models.** *Collaboration and innovation is needed to commercialize the technologies and services that are not viable today, but will be essential for reducing exposure to supply risks in tomorrow's markets.*

Accomplishing this checklist will require overcoming commercial barriers. Companies that want to proactively address risks still need to see a return on their investment in new technologies and services. Likewise, companies developing and selling solutions will need to make money on those innovations. But water and energy prices, infrastructure, and coordination all present challenges to companies doing business at the water-energy nexus. Overcoming today's barriers will require new ideas, approaches, and collaboration.

Innovation at the water-energy nexus involves thinking differently about how industries meet their customers' water and energy needs. Specifically, instead of trying to expand the supply of limited freshwater and fossil fuel resources, companies can find opportunity in reducing demand and scaling alternatives. This report highlights several ideas to do this, including:

- Inclusive approaches that recognize the benefits of gender mainstreaming and local stakeholder engagement in water and energy resource decisions.
- Ambitious cross-sector goals for end-use energy efficiency, water reuse, decentralized clean energy, and smart infrastructure.
- Financial due diligence with innovative and forward-thinking approaches to pricing carbon and valuing water.

Participating in partnerships to test these ideas can help turn them into reality. Companies can share costs and risks while learning about new technologies. They can create joint data and reporting protocols, share best practices, and work with governments in public-private partnerships. These types of efforts are needed to scale the solutions that will help ensure water and energy resources are available for companies and communities in a world approaching 9 billion people over the next 25 years.

Introduction

Global trends suggest the next 25 years will see increasing demand and competition for water and energy resources. The world's population is projected to grow from 7 billion today to 9 billion by 2040 (UN 2015a). That growth, together with trends in urbanization, mobility, economic development, international trade, cultural and technological changes, and climate change, will drive increased competition among water, energy, agriculture, and other sectors (FAO 2014).

Increasing demand for water and energy will force tradeoffs in arid or water-stressed areas. These resources are interconnected in what is referred to as the water-energy nexus (Figure 1).[1] Massive amounts of freshwater are needed to cool thermoelectric power plants; drive turbines that create hydropower; and extract and process oil, gas, coal, metals, and chemicals. Similarly, significant energy resources are needed to heat, treat, desalinate, and transport water.

Two questions are examined in this report:

- Where are companies facing risks at the nexus of water and energy resource challenges?
- What are the opportunities for companies to reduce exposure to these risks and meet customers' needs in tomorrow's markets?

Figure 1 | **The Water-Energy Nexus: Connections between Two Crucial Resources**

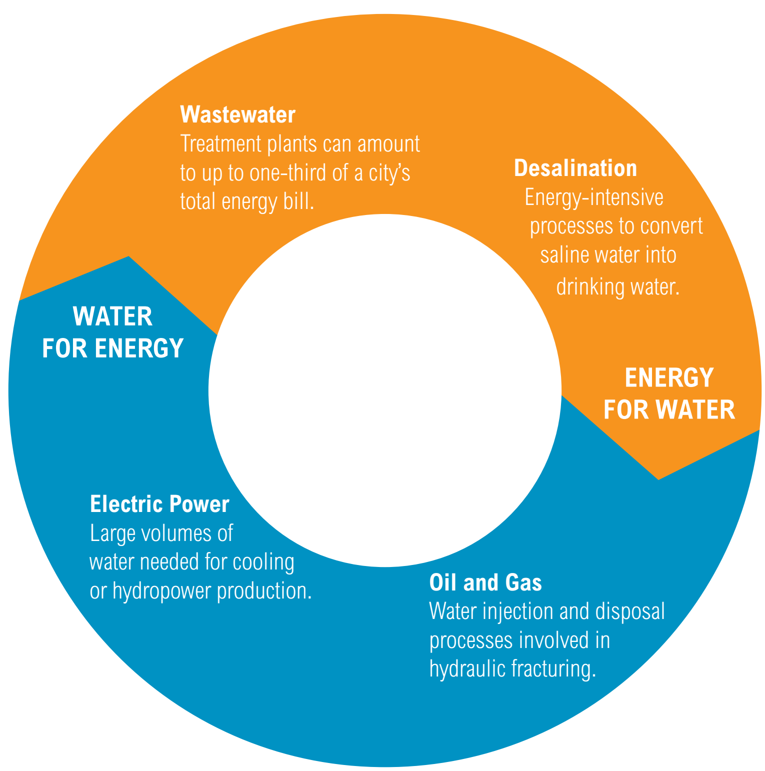
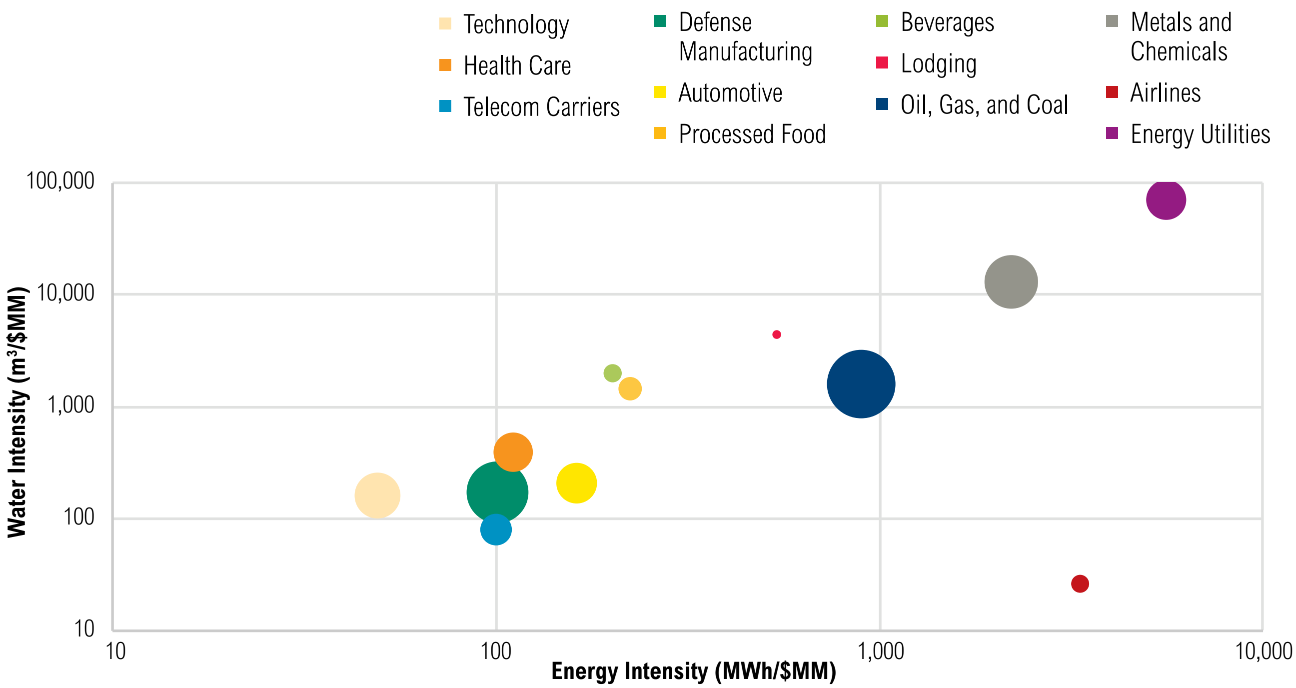


Figure 2 | **Water and Energy Intensity of Major Industries**



Note: Bubble area proportional to total industry revenue.

Source: Industry data for 2013 accessed via Bloomberg Terminal (Bloomberg 2015).

Increased demand and competition for water and energy has implications for many of the world's largest industries that rely on an available, affordable supply of both resources (Figure 2). Energy utilities, and producers of metals and chemicals, and oil, gas, and coal are the most energy- and water-intensive industries. Others, including the automotive industry, create products that rely on metals, chemicals, oil, and gas. Technology, health care, and telecommunication companies are major customers of—and suppliers to—the metals, chemicals, and energy industries. Such relationships suggest water and energy are drivers of value-chain risk and opportunity.

Companies that anticipate a growing population that will demand more water and energy, also anticipate business risks related to scarcity and volatility, including increased costs, regulations, and supply vulnerabilities and disruptions. "Water crises" and "energy price shock" now consistently rank in the top 10 (numbers 1 and 6, respectively, in 2015) of the World Economic Forum's annual Global Risks report (WEF 2015).

This report builds on World Resources Institute research profiling risks and opportunities at the water-energy nexus, specifically "Water and Watts" (Chandler, Creech, and Metzger, et al. 2009); "Global Shale Gas Development: Water Availability & Business Risks" (Reig, Luo, and Proctor 2014); and "Opportunities to Reduce Water Use and Greenhouse Gas Emissions in the Chinese Power Sector" (Seligsohn, Wen, and Hanson, et al. 2015).

It also draws on research and experiences from GE's Ecomagination and Water & Power teams, who provided valuable commercial perspectives on the types of risks emerging for industries worldwide at the water-energy nexus and the opportunities to address them.

Doing business at the water-energy nexus is not easy. Companies face regional, national, and local barriers. Energy and water infrastructure development is not typically well-coordinated across—or even within—jurisdictions. Constraints on water and energy resources are rarely integrated into infrastructure development or planning. Public investment in infrastructure is also lacking; in the United States, an extrapolation of the funding gap for water and wastewater infrastructure suggested it could reach $144 billion by 2040 (ASCE 2011). Finally, water and energy are not typically priced to reflect their true scarcity, societal costs, or value to business. This makes building a business case on traditional return on investment difficult and requires companies to think ahead to factor in future costs and other risks that will emerge. Companies will need innovative business models, technologies, and partnerships to overcome today's barriers, address emerging risks, and meet the needs of 9 billion people (Box 1).

Three regions will be among the first to act on water-energy nexus issues that will later affect other regions (Figure 3). The Middle East and North Africa (MENA) already faces extremely high water stress and relies on energy-intensive desalination to meet industrial, agricultural, and domestic water demands. China and the United States, which are among the world's largest energy producers and consumers, expect increased water stress by 2020.

This report looks at energy use for desalination in the Middle East and North Africa (MENA), water use for electric power in China, and water use for unconventional oil and gas development in the

BOX 1 | MEETING THE WORLD'S WATER AND ENERGY NEEDS

As the global population grows from 7 billion to 9 billion over the next 25 years, countries and industries face a daunting challenge in meeting water and energy needs. Currently 660 million people do not have access to improved sources of drinking water (WHO and UNICEF 2011) and a billion do not have electricity (IEA 2015).

The good news is that over the past 25 years, more than 2.5 billion people have gained access to improved water sources and approximately 2 billion have gained access to electricity (WHO and UNICEF 2011). However, the world's supply of freshwater is finite, and today's energy must be replaced by cleaner sources to protect air quality and reduce the risks of climate change.

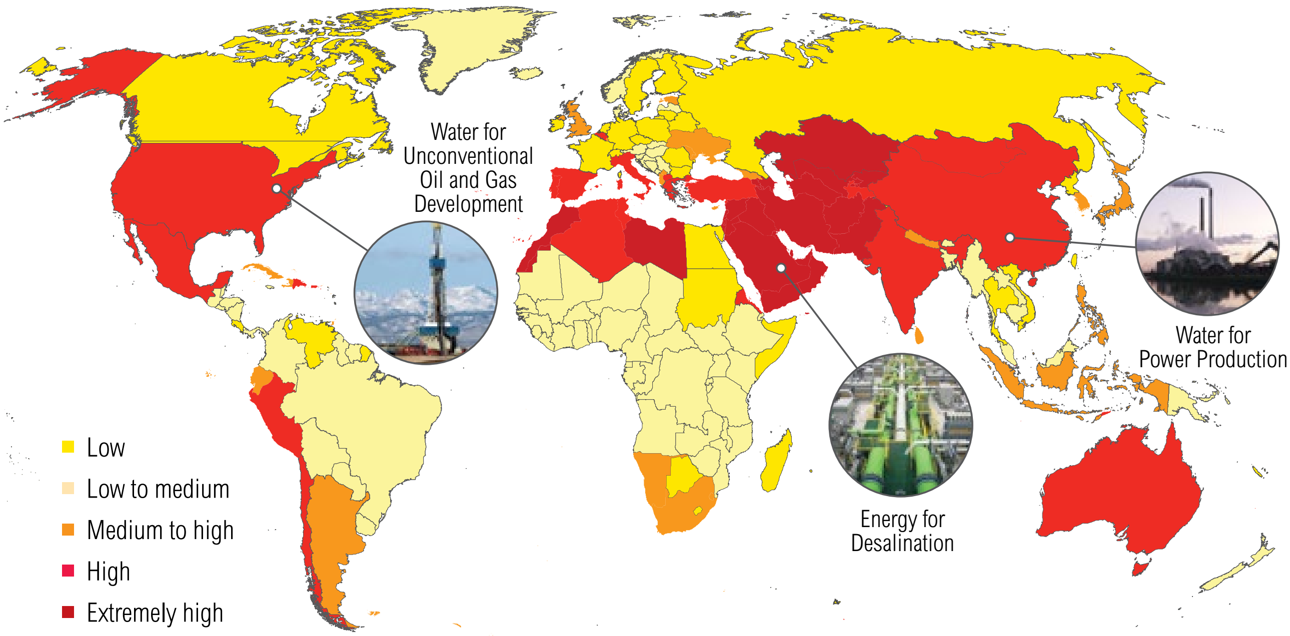
Public and private sector leaders have recognized that socioeconomic development and human well-being depend on current and future access to clean water and energy. In 2015, they acknowledged the scale of the challenge and established global ambitions for water and energy access in the United Nations Sustainable Development Goals:

- Goal 6. Ensure availability and sustainable management of water and sanitation for all. This goal includes targets for "universal and equitable access" and water efficiency across all sectors, as well as for international cooperation in areas like desalination, water efficiency, wastewater treatment, recycling, and reuse technologies.

- Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all. This goal includes similar universal access targets, as well as doubling the global rate for energy efficiency gains and a "substantial" increase in the portion of global energy demand met by renewable sources. It also includes targets related to international research cooperation on energy infrastructure and clean energy technology.

Other global priorities, such as addressing climate change, gender equality, and industry, innovation, and infrastructure, link to the water-energy nexus. Together, they create a shared platform for public and private sector action on global economic, environmental, and social priorities.

Figure 3 | **Projections of Water Stress in 2020 under Business-as-Usual Climate and Socioeconomic Scenarios, by Country**



Note: Water stress is the ratio between total water withdrawals and available renewable surface water in a subcatchment.

Source: Water stress projections from WRI Aqueduct (Luo, Young, and Reig 2015).

Doing business at the water-energy nexus is not easy. Companies face regional, national, and local barriers. Energy and water infrastructure development is not typically well-coordinated across—or even within—jurisdictions.

United States. Because of their scale and circumstances, these industries and regions are confronting risks at the water-energy nexus today. MENA is among the driest regions on the planet. China is home to the world's largest thermoelectric power fleet. The United States, the largest consumer of oil and gas, has recently become a large producer. Their examples can inform and inspire action in other regions.

The conclusion discusses the types of risk and opportunities these regions and industries are facing, offers ideas for thinking differently about solutions at the water-energy nexus, and provides a high-level checklist based on common priorities emerging across the three regions.


colors
MOVIE STARTING WITHOUT YOU?

ENERGY FOR WATER: DESALINATION IN THE MIDDLE EAST AND NORTH AFRICA

As populations grow in the Middle East and North Africa (MENA), meeting basic water needs becomes increasingly challenging and costly. MENA is one of the most water-scarce regions in the world and many of its countries already use desalination to address a growing gap between water supply and demand. All 21 countries in the region are expected to fall below the World Health Organization's water poverty line (1,000 cubic meters per capita per year) by 2030 (UNDP 2013).

This section looks at MENA's example to illustrate:

- Energy risks for water providers and desalination plants (and, indirectly, for their customers)
- Opportunities to reduce exposure to energy risks and meet future water needs

Where Are Energy Risks and Desalination Costs Creating Challenges for Water Providers?

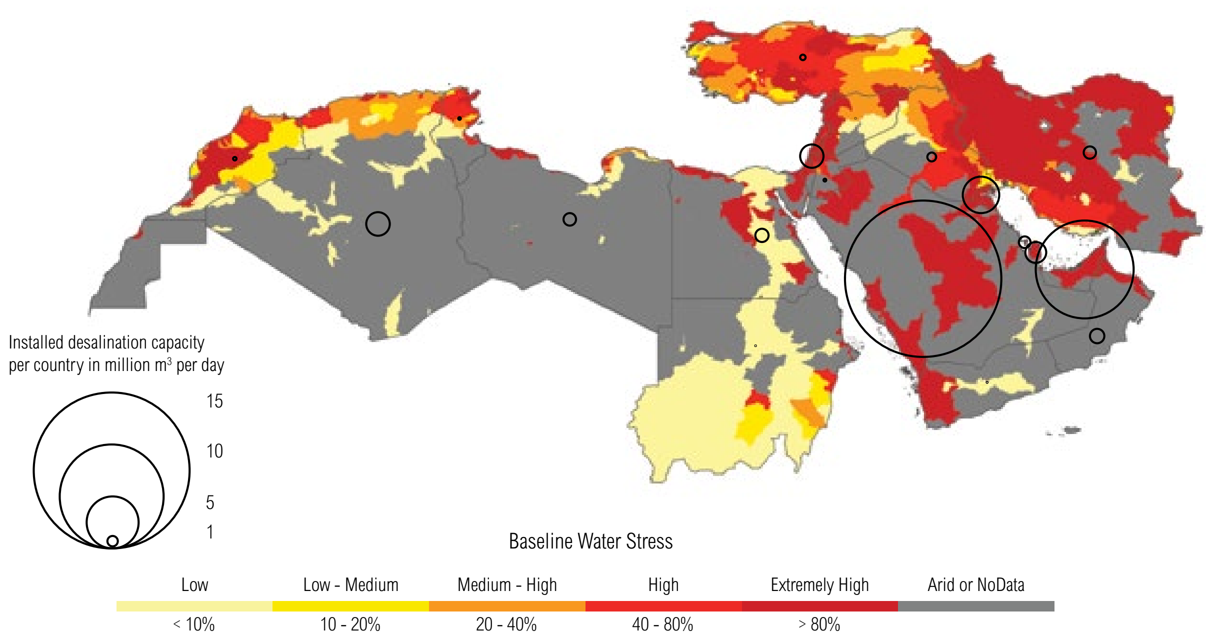
Water stress is high or extremely high in the Middle East and in some coastal sections of North Africa. Energy-intensive desalinization is widely used in Israel and the Arabian Peninsula (Figure 4).

Water providers face an immense challenge as populations and resource demands grow in a region where freshwater is already scarce. The availability of renewable water—water from rivers and aquifers that are recharged by precipitation—is already under 2,000 cubic meters per capita per year, which is just a fraction of the world average of 7,240 cubic meters per capita per year (UNDP 2013). By 2050, two thirds of the region will have renewable water availability of less than 200 cubic meters per capita per year and the entire region will face a water gap somewhere between 85 billion and 283 billion cubic meters per year due to a 50 percent growth in population, economic development, and climate change impacts.[2] Climate change impacts like extreme heat and drought exacerbate the challenge of providing sufficient freshwater to meet domestic, agricultural, and industrial needs. Intelligence agencies expect water scarcity to contribute to future instability in an already politically volatile region (DNI 2012).

Although improved water management will be critical to reducing this severe water gap, unconventional water sources like desalination will be needed as well. The World Bank estimates that an additional 72 billion cubic meters of water per year—more than 85 percent of it in Iraq, Saudi Arabia, Morocco, Egypt, and Yemen—will need to be provided through desalination by 2050 (World Bank 2012).

Current desalination technologies require considerable energy inputs. Reverse osmosis uses only electricity, while thermal desalination methods also require heat (Box 2). Desalination consumes

Figure 4 | **Baseline Water Stress and Desalination Capacity in the Middle East and North Africa**



Source: Water stress data from WRI Aqueduct (WRI 2015) and desalination data courtesy of Global Water Intelligence (GWI 2015).

BOX 2 | WATER DESALINATION TECHNOLOGIES

Three technologies provide most desalination worldwide: reverse osmosis, multi-stage flash distillation, and multi-effect distillation. Reverse osmosis, a membrane-based technology that is the dominant desalination technique used worldwide, requires increasing amounts of electricity proportional to the amount of salt to be removed. For this reason, reverse osmosis is often split into separate categories based on whether the water source is saltier seawater or brackish water. Multi-stage flash distillation and multi-effect distillation are thermal desalination techniques that require heat in addition to electricity.

Historically, the thermal techniques have been better suited for the Persian Gulf because of seawater's high temperature, salinity, turbidity, and concentration of marine organisms, each of which contributes to higher costs for reverse osmosis pretreatment. However, recent advances in membrane and pretreatment technologies have made reverse osmosis cost competitive even in Gulf Cooperation Council nations bordering the Persian Gulf.

Other desalination technologies include electrodialysis, electrodeionization, vapor compression, nanofiltration, and forward osmosis, but combined they made up less than 5 percent of total desalination capacity in 2011. These options are primarily used to improve the efficiency of multi-stage flash distillation or multi-effect distillation or as a pretreatment step for reverse osmosis.

Sources: IRENA 2012; Bauer, Philbrick and Vallario 2014.

75 terawatt hours of electricity globally every year,[3] and the International Renewable Energy Agency estimates more than 99 percent of this energy comes from fossil fuels (IRENA 2015). For countries in MENA, that means diverting a significant portion of their oil and gas resources to power desalination plants. In the United Arab Emirates, for example, desalination accounts for nearly 25 percent of total primary energy consumption (World Bank 2012). Likewise, Saudi Arabia uses 25 percent of its oil and gas production to generate electricity for desalination plants (UNDP 2013). In Kuwait, energy consumed for desalination cogeneration, which uses waste heat from electricity production for desalination, is expected to equal the country's current fuel oil production by 2035 (UNDP 2013).

Water providers, and the countries and communities they serve, face economic, environmental, and social risks associated with desalination's energy demands, including greenhouse gas (GHG) emissions and climate change. MENA is likely to face some of the most disruptive impacts of climate change, including extreme heat, heightened water scarcity, and impaired food security (World Bank 2014). Current means of powering desalination plants create GHG emissions that further increase the risk of these impacts. The World Bank estimates that under a business-as-usual scenario, the natural gas- and oil-powered desalination plants needed to produce 90 billion cubic meters of desalinated water in 2050 will emit 270–360 megatons of CO_2 annually (World Bank 2012). These emissions contribute to the high carbon intensity of the Gulf Cooperation Council countries—Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and United Arab Emirates—all six of which are among the top 10 countries worldwide in carbon emissions per capita (World Bank 2011). Future GHG mitigation efforts could lead to political and social opposition to fossil fuel-powered desalination, resulting in increased regulation and financial risks.

Desalination is a costly way to produce water, and is usually considered only after water demand reduction and supply expansion techniques have been applied. For comparison, desalination using conventional energy resources was estimated to cost approximately $1.30 per cubic meter of water per year in 2010, compared with $0.02 per cubic meter per year for conserving water by improving agricultural practices, $0.30 per cubic meter per year for increasing domestic and industrial water reuse, and $2.00 per cubic meter per year for reducing domestic and industrial demand (World Bank 2012). Approximately half the cost of desalination is capital expenditure and one third to half is from energy use (World Bank 2012).

Increased reliance on desalination, therefore, creates additional exposure to energy price fluctuations. Historically, the MENA region's energy subsidies—which make up 8.6 percent of regional GDP and 48 percent of global energy subsidies—have kept energy prices low, but changes to this system would increase desalination costs greatly and potentially alter the choice of both desalination technology and energy source (IMF 2014). In some areas, eliminating natural gas subsidies could nearly double water costs for certain desalination technologies, from $0.85 to $1.60 per cubic meter (CEBC 2014). Although cogeneration is often cited as a way to reduce desalination costs, electricity demand is only high enough during the summer months to make cogeneration cost effective (CEBC 2014).

Water distribution adds costs to desalination, particularly when water is delivered to communities at high altitudes or far inland. For example, Sana'a, Yemen, the world's third fastest growing capital city will require 33 times more water by 2050, but the city's high altitude adds transportation costs of $2 per cubic meter to desalination costs of $2–$3 per cubic meter (World Bank 2012). Other countries, including Iran and Jordan, will face expensive challenges in transporting water from desalination plants to their inland capitals (World Bank 2012).

What Are the Opportunities for Water Providers to Reduce Exposure to Energy Risks and Meet Future Needs?

To meet customers' future needs, water providers in MENA will need desalination solutions that increase energy efficiency and tap cleaner energy sources. They will also need to look for innovative, affordable water solutions beyond desalination.

Energy efficiency and recovery in desalination. Overall estimates for efficiency potential suggest several countries in the region can reduce energy consumption for desalination by 20 percent or more by 2025 (Fath, Sadik, and Mezher 2013). Water providers can reduce exposure to energy costs with efficiency gains—but options vary by technology. The efficiency of reverse osmosis desalination, for example, has improved almost 10-fold in the past 40 years (World Bank 2012). Although the central technology is nearing its maximum practical efficiency (Elimelech and Phillip 2011), water providers can still look for efficiency gains with improved pretreatment and membrane cleaning techniques, both of which reduce fouling and scaling and thereby improve plant efficiency (Chesters and Armstrong 2013).

Thermal desalination technologies can also be improved through energy recovery (World Bank 2012). Technologies like multi-effect distillation, which are less technologically mature than established techniques, present an opportunity for water providers to support research. In hybrid cogeneration plants, multi-effect distillation can be combined with reverse osmosis (Ng, Thu, and Oh, et al. 2015). The distillation can run on waste heat from power generation, while the power itself can be used for desalination using reverse osmosis. This combination offers other benefits; it reduces total dissolved solids and adds flexibility to adjust for daily or annual variations in energy and water demand. Such projects are in preliminary stages, but water providers can invest in research, development, and demonstration (RD&D) to help them reach commercial scale (Iaquaniello, Salladini, and Mari, et al. 2014).

Alternative water resource solutions. Water providers can also help study, map—and ultimately tap—large brackish groundwater resources located throughout the MENA region (World Bank 2012). Brackish water costs half as much to desalinate as seawater because it has less salt thus requires less energy. However, it does require pumping from underground aquifers, making cost comparisons highly variable based on the depth of the aquifer. In addition, the hydrological impact of pumping brackish water on fresh groundwater resources varies based on local geology (Wythe 2014). Water providers can help with the significant investment needed to survey this groundwater so brackish desalination can reach a larger scale in the region (World Bank 2012).

Alternative energy resource solutions. To reduce desalination's carbon intensity and reduce exposure to future fossil fuel costs, water providers can use renewable energy resources. Although many renewable energy sources are available in MENA, concentrated solar power (CSP) and solar photovoltaic (PV) are the region's most exceptional opportunities for clean power (Table 1). Because 22–26 percent of all sunlight hitting Earth's land-mass falls in MENA, full use of CSP there would provide 20 times the amount of primary energy used globally (World Bank 2012).

CSP and PV each have unique advantages as energy sources for desalination. As a form of thermal energy production, CSP is ideal for coupling with thermal desalination technologies that can use its waste heat. CSP has the added benefit of providing baseload power using thermal storage, reducing the need for backup energy sources (IRENA 2015). CSP has large water requirements, which can be mitigated through dry cooling systems or effective integration with desalination to make use of sea-water for cooling (Palenzuela, Alarcón-Padilla, and Zaragoza 2015). However, the efficiency of thermal CSP cogeneration is reduced in coastal areas because of corrosion from the salty air (Kraemer 2013). Inland CSP plants can provide electricity for seawater reverse osmosis desalination near the coasts, but this precludes the opportunity for cogeneration and makes CSP cost prohibitive. Still, the European Academies Science Advisory Council predicts that CSP will reach cost competitiveness in MENA between 2020 and 2030, with half the cost reductions coming from economies of scale and the other half from technology developments (Pitz-Paal, Amin, and Bettzüge, et al. 2013).

Solar PV is a more advanced technology. Its relatively low cost and simple grid integration makes it ideal for electricity generation for reverse osmosis (Box 2). However, electricity storage costs remain a barrier to widespread solar PV use for desalination.

Table 1 | **Renewable Energy Potential in the Middle East and North Africa**

ENERGY SOURCE	ENERGY POTENTIAL (TERAWATT HOURS/YEAR)
Concentrated Solar Power (CSP)	462,000
Coastal CSP	964
Solar photovoltaic	356
Geothermal	300
Wind	300
Hydropower	182
Biomass	111

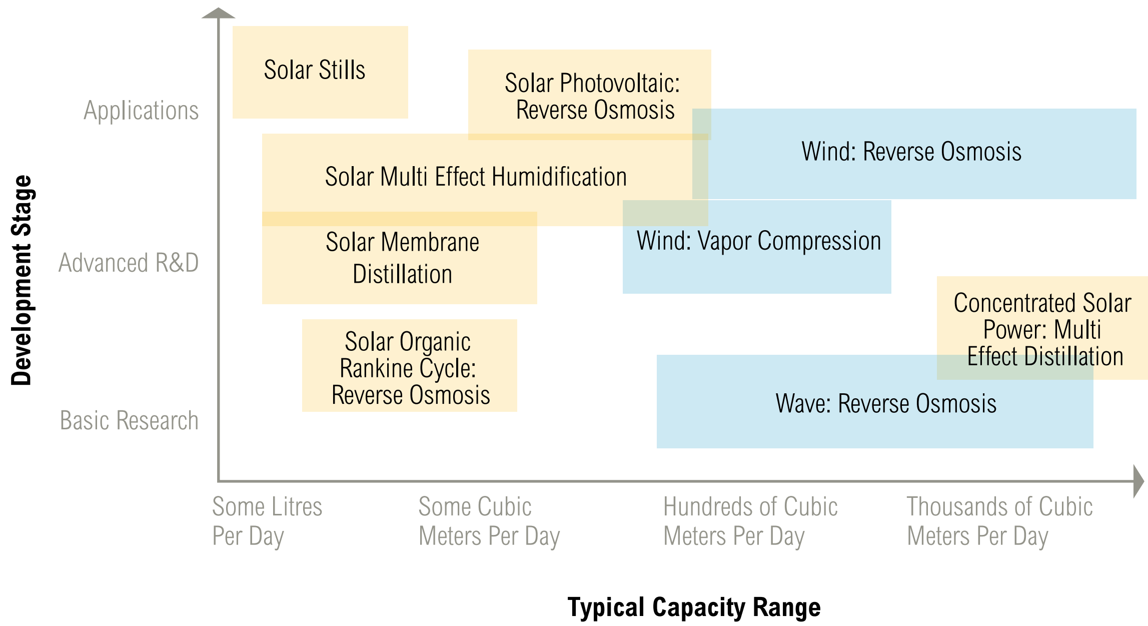
Source: World Bank 2012.

BOX 3 | SOLAR DESALINATION IN AL KHAFJI, SAUDI ARABIA

Plans were announced in January 2015 to develop the world's first large-scale solar-powered desalination plant in Al Khafji, Saudi Arabia. The $130 million plant is scheduled to be completed by early 2017 and supply 60,000 cubic meters of water per day through seawater reverse osmosis, with dissolved air flotation and ultrafiltration as pretreatment steps. A 15-megawatt photovoltaic plant will power the system during peak hours, and the grid will provide electricity when solar energy is unavailable.

Source: water-technology.net 2015.

Figure 5 | **Development Stage and Capacity of Renewable Energy Desalination Technologies**



Source: Adapted from IRENA 2015.

Other renewable energy-desalination combinations include technologies that tap wind and wave energy. Desalination technologies are in different stages of research and development (Figure 5).

The applicability of renewable energy sources to desalination varies with local water characteristics, solar availability, and economics. A single approach is unlikely to meet desalination needs across MENA. Instead, water providers can test and assess a portfolio of renewable desalination options for future commercialization.

Based on their expected lifespans, all desalination plants in the region will be decommissioned by 2045, according to World Bank estimates. For renewable desalination to fill this gap, the Bank estimates that new options must be technologically mature and cost competitive by 2030 (World Bank 2012). Substantial research, development, and pilot testing by businesses will be necessary to ensure that renewable desalination can provide water for the region in 2050 and beyond.

Reusing other water and energy resources. For urban water supply and treatment, wastewater reuse is far more energy-efficient than current seawater desalination options. Meanwhile, the energy embedded in wastewater can power an entire water treatment plant. The energy content of municipal sewage can be two to four times greater than the energy required to treat it (WERF 2011). Wastewater is an unexploited energy resource that current technologies and practices do not fully capitalize. Innovative technologies, using improved anaerobic digestion and methane capture, can turn what otherwise would be waste and pollution into useful products like natural gas, compost, and biochar. A WRI analysis of Qingdao, a city in China, found wastewater treatment would require less than 1 kilowatt hour per cubic meter, compared with 4 kilowatt hours per cubic meter for desalination from seawater (Figure 4.1 in Box 4; Wen, Zhong, and Fu 2014). Options for providing growing cities with clean water and wastewater treatment are discussed in Box 4.

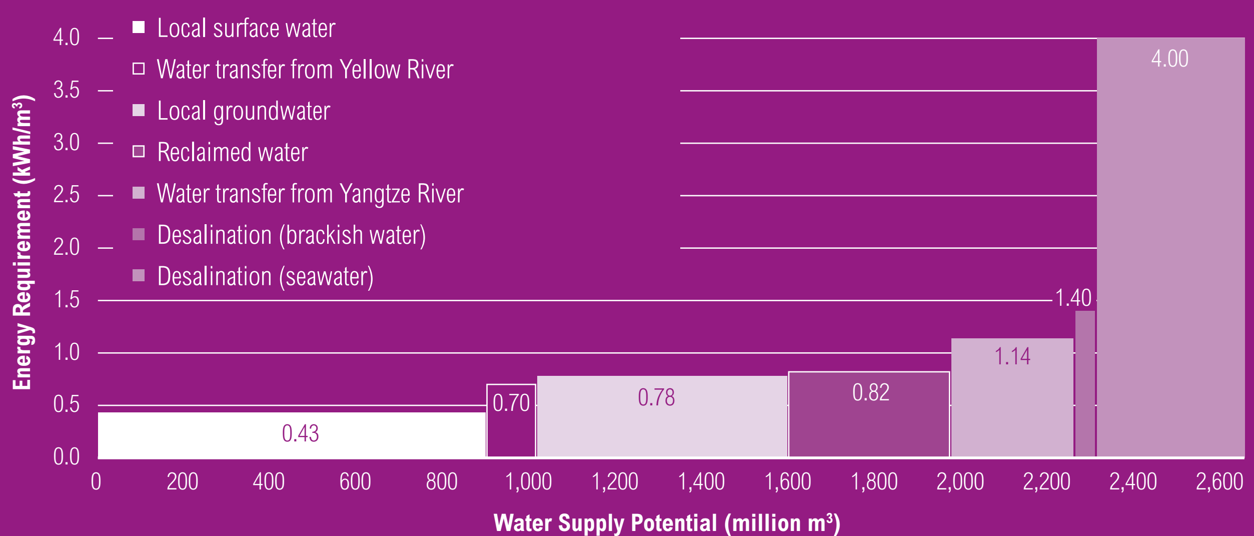
BOX 4 | OTHER ENERGY-FOR-WATER INNOVATION OPPORTUNITIES IN GROWING CITIES

As the world urbanizes, cities must keep up with demand for water and wastewater treatment. Millions of new residents will need drinking water and sanitation services. China, for example, has increased investment in facilities to increase cities' capacity to treat urban wastewater from 50 percent to 85 percent over the past decade (China State Council 2012). Urban areas in India had the capacity to treat only 31 percent of wastewater as of 2011 (Kamyotra and Bhardwaj 2011).

How water needs are met will have important implications for energy demand in cities, where electricity used for water treatment can be one third of a city's energy bill (Copeland 2014). These energy demands can be expected to grow globally as developing countries improve infrastructure and developed countries require higher levels of water treatment for reuse and discharge to the environment. In the United States, for example, energy demand from publicly owned water and wastewater facilities increased nearly 40 percent and 75 percent respectively from 1996 to 2013 (EPRI 2013). In total, those facilities use 70-75 billion kilowatt hours of energy per year—enough to power 6.75 million homes (USEPA 2009). Fortunately, in making decisions about sourcing and treatment options, cities have opportunities to minimize energy demand for water. Examples from two Chinese cities illustrate these opportunities:

- **Tapping energy efficient water sources.** In Qingdao, a city in China's Shandong Province, demand for water is expected to reach 1.48 billion cubic meters by 2020. However, the provincial government will limit the city's total water use to 1.47 billion cubic meters by that year. To meet demand, Qingdao will need to conserve water and use unconventional sources (water reuse, desalination) that are excluded from quotas. In doing so, it will need to consider the energy implications of its future water sources (see Figure 4.1). Based on a World Resources Institute (WRI) analysis, reusing and reclaiming freshwater from wastewater streams—by treating it to drinking water standards—is Qingdao's most cost-effective option when local surface water, groundwater, and diversions from the Yellow River are exhausted. It would require less than 1 kilowatt hour per cubic meter, compared with 4 kilowatt hours per cubic meter for desalination from seawater (Wen, Zhong, and Fu 2014).
- **Using the energy in wastewater.** Xiangyang, a city in China's Hubei Province is turning sludge into energy. China's Ministry of Housing and Urban Rural Development invited WRI to independently review the benefits of the process that Xiangyang is testing. WRI found the treatment plant can create 45 million cubic meters of compressed natural gas over an operating period of 21 years (enough to replace nearly 16 million gallons of gasoline) while also reducing the plant's greenhouse gas emissions by 98 percent and producing valuable biochar from recovered nitrogen and phosphorous (Fu and Zhong 2015).

FIGURE 4.1 | THE WATER SUPPLY POTENTIAL AND ENERGY CONSUMPTION OF QINGDAO'S WATER SOURCES

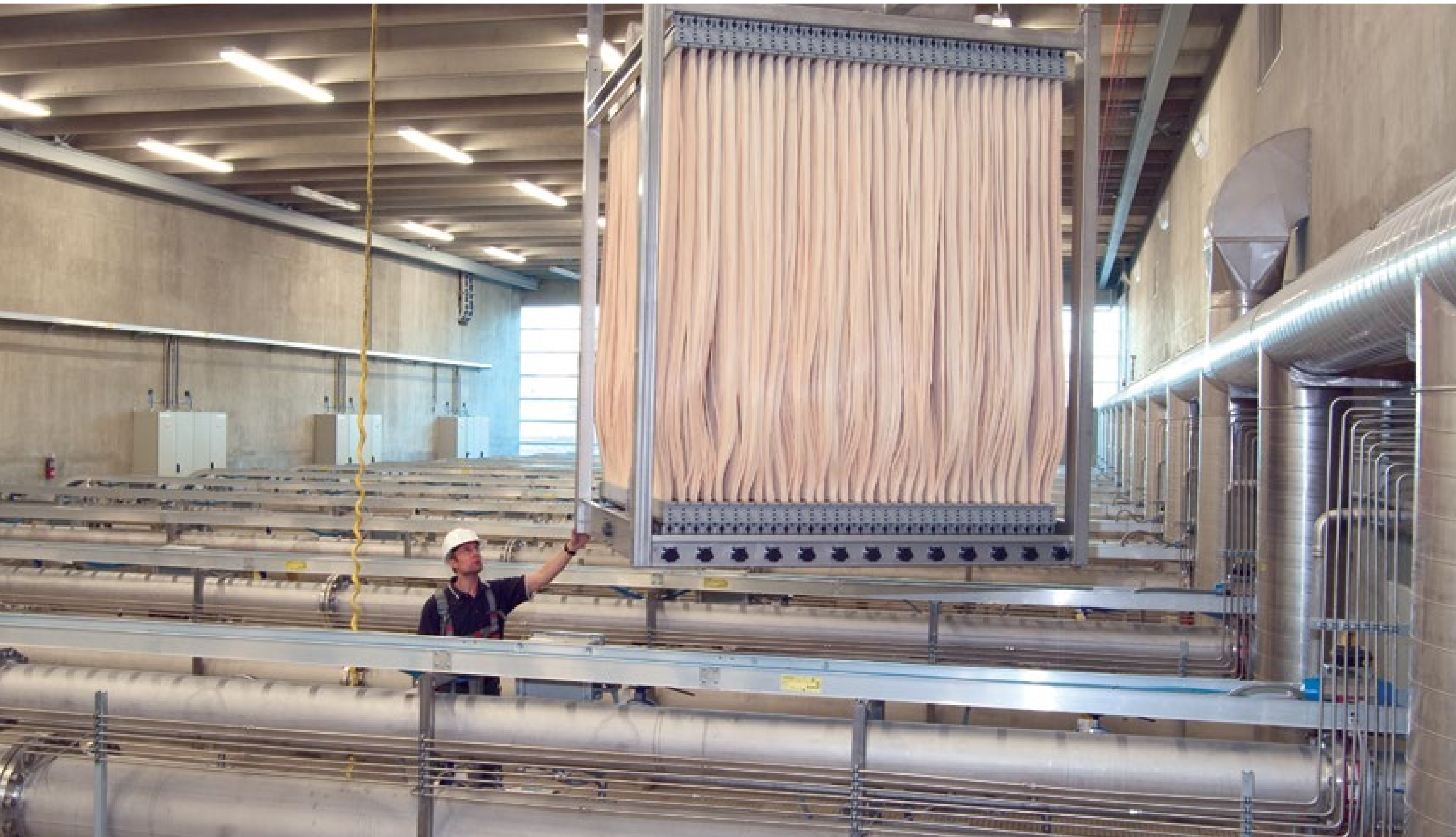


Source: Water Energy Nexus in Urban Water Source Selection (Wen, Zhong, and Fu 2014).

***Thinking differently:* gender mainstreaming and local stakeholder engagement in water resource decisions.** Perhaps the most direct way to plan for the future is to work with those who need and use water resources. In many cases, that means involving women in developing countries, who on average, spend 25 percent of their day collecting water for their families (UN 2015b). Companies that rely heavily on water, such as Unilever and Coca-Cola, are recognizing that empowering women in Africa and elsewhere can help support economic development and encourage stewardship of local water supplies (WaterAid 2015). These companies are participating in public-private partnerships to improve water access and support gender mainstreaming to include a diversity of perspectives in critical resource planning decisions. Water providers in MENA can join these initiatives to explore options for including women in the design, planning, and implementation of projects to meet local water needs. Efforts in Kenya, for example, demonstrate why an inclusive approach is so important:

Women typically use water for multiple purposes including productive uses such as small gardens, raising animals, and washing and selling vegetables. As these are traditionally women's activities, the lack of adequate water has a higher impact on women's economic development, health and hygiene. As women are also usually responsible for collecting water, they spend hours every day on this activity. In this sense, there is a very different impact of water on women and men, and it is important to ensure that these implications are understood so that unintended negative repercussions are curtailed when designing, planning and implementing water programs (USAID 2014).

Water providers can find tools and guidance from development agencies (GWA 2006) and reference the "significant body of evidence which shows that the success of water projects improves when the design and implementation take into account the views and interests of both women and men" (USAID 2014). Evidence suggests it will also be essential for water providers in MENA to engage women when creating processes and models for siting, distributing, purchasing, and financing clean energy investments, which will be critical to future desalination plants (Alstone, Niethammer, and Mendonça, et al. 2011).



WATER FOR ENERGY: ELECTRIC POWER IN CHINA

As China builds new power plants to meet future electricity needs, it confronts tradeoffs between energy and water. China is home to the world's largest fleet of thermoelectric power plants, most of which are coal fired and require a significant supply of freshwater for cooling (China Electricity Council 2013). Nearly 60 percent of China's coal-fired power generation is in regions facing high or extremely high water stress.

This section looks at China's example to illustrate:

- Water supply risks for electric power providers (and, indirectly, for their customers)
- Opportunities to reduce exposure to water risks

Where Is Water Stress Creating Risks for Electric Power Production?

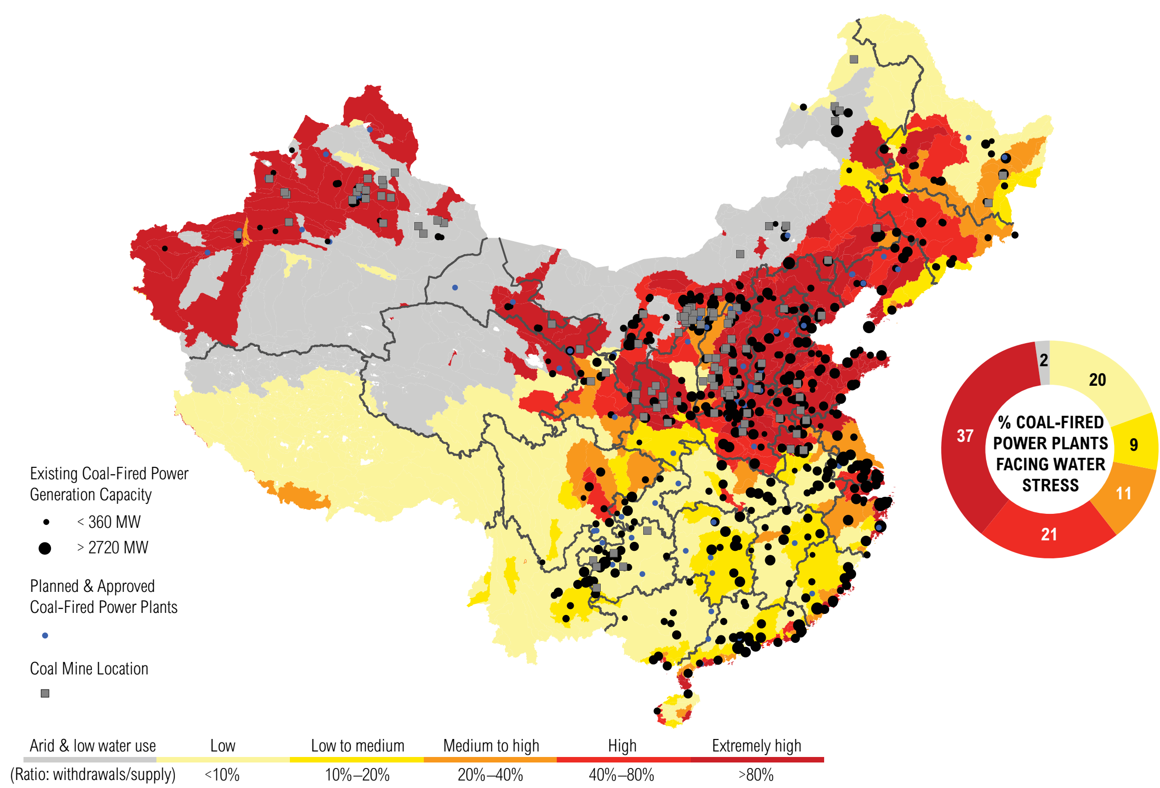
Most of China's coal-fired power plants are in regions of significant water stress (see red areas in Figure 6).

In thermoelectric power plants, water is needed for cooling, as well as for generating steam to drive turbines (as it does directly at hydroelectric stations). In 2014, more than 90 percent of China's electricity came from thermoelectric and hydroelectric power plants (Figure 7). These plants depend heavily on local water supplies, their water use depending on their size, location, and cooling technology.[4]

Renewable energy technologies are generally less water intensive with wind and solar photovoltaic technologies having relatively negligible onsite water requirements.

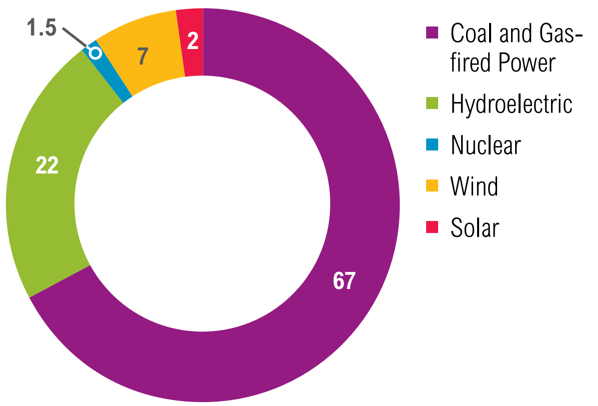
Water scarcity is likely to become an increasingly important risk factor for China's electric power providers to manage while seeking to meet customers' future electricity needs. Current projections suggest thermoelectric and hydroelectric power generation capacity will increase by 80 percent from 2012 to 2030 (Figure 8). Analyses suggest more than 40 percent of China's proposed new coal-fired capacity (259 gigawatts) will be concentrated in six dry provinces (Inner Mongolia, Shanxi, Shaanxi, Hebei, Ningxia, and Gansu; CoalSwarm 2015). Meanwhile, projections to 2040 suggest climate change will intensify water stress in drier provinces by 40–70 percent over water stress seen today (Luo et al. 2015).[5]

Figure 6 | **Nearly 60 Percent of China's Coal-Fired Capacity Is in Regions of High or Extremely High Water Stress**



Source: Water stress data from WRI Aqueduct (WRI 2015) and desalination data courtesy of Global Water Intelligence (GWI 2015).

Figure 7 | **More than 90 Percent of China's Electric Generation Capacity is from Thermoelectric (Coal, Gas, Nuclear) and Hydroelectric Power Plants**



Source: China Electric Yearbook 2014 (China Electricity Council 2015).

As China meets growing energy demands, electric power providers will be making decisions about fuel sources and cooling technologies that ultimately determine their water needs. Power plants "withdraw" and "consume" water.[6] Many thermoelectric power plants withdraw significant amounts of water from a nearby lake or river, use it for cooling and steam generation, and then return it to the source. Depending on the cooling technology, some amount of water is consumed (evaporates) and not returned to its original source.

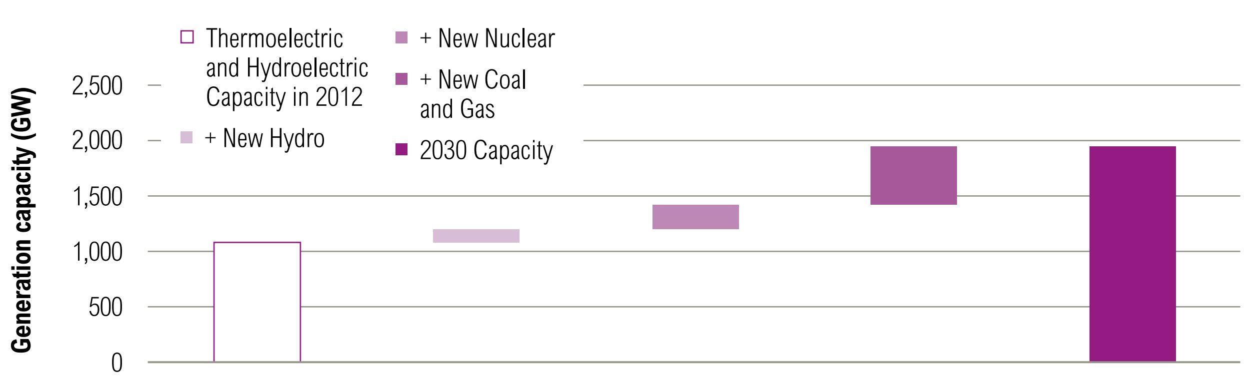
In China and elsewhere, power plants are required to obtain a water permit and pay a water resources fee based on the amount of water withdrawn. Scarce water resources could drive competition for these permits among energy, agricultural, industrial, and domestic users possibly resulting in increased fees; higher prices could also result from building new infrastructure to bring water from elsewhere. For example, thermoelectric power plants are expected to face higher costs to use water delivered by the South-to-North Water Transfer Project (NDRC 2014a).

Finally, water-reliant electric power providers will face tradeoffs and costs related to potential disruptions during heat waves and droughts. In 2010, for example, when a severe drought hit China's water-abundant south, hydropower generation from that region dropped by 30 percent (International Rivers 2014). Likewise, during heat waves, thermoelectric plants may have to cut down production or operate at lower efficiency if the surface water becomes too warm for cooling. China and other countries also have regulations that limit the temperature at which water can be returned to its source (to avoid damage to aquatic ecosystems), which can prove challenging in times of drought and extreme heat.

What Are the Opportunities for Electric Power Providers to Reduce Exposure to Water Risks?

Electric power providers in China are exploring opportunities to reduce their reliance on scarce

Figure 8 | **China's Thermoelectric and Hydroelectric Capacity Is Expected to Increase by 80 Percent from 2012 to 2030**



Source: The Future of China's Power Sector (BNEF 2013).

freshwater resources and exposure to related physical, regulatory, and financial risks. They can prioritize water-efficient fuel sources and cooling technologies, while boosting efficiencies at existing and new power plants. Likewise, using and reusing alternative water sources (e.g., wastewater, seawater, and brackish water) will help reduce future strain on limited freshwater supplies. The Chinese government is already acting to support such efforts (Box 5).

Technologies for clean fuel, water-efficient cooling, and plant efficiency. Electric power providers can find win-win opportunities with technologies that reduce their exposure to water risks and deliver clean energy, while also improving air quality and reducing greenhouse gases (Seligsohn et al. 2015). China is rapidly moving beyond fossil fuels, aiming to increase the share of such alternative sources to about 20 percent of primary energy consumption by 2030. Wind and solar photovoltaic

BOX 5 | CHINA'S POLICIES TO SUPPORT WATER EFFICIENCY IN THE ELECTRIC POWER SECTOR

The Chinese government has recognized the magnitude of water challenges in its electric power sector, and started to take actions to mitigate the risks. Meanwhile, some of the nation's new energy policies to combat climate change and reduce air pollution, have significant implications for how electric power providers will use freshwater resources (Table 5.1).

TABLE 5.1 | CHINESE POLICIES AND THEIR INTENDED IMPACT

POLICY	IMPACT ON THE POWER SECTOR/WATER RESOURCES
Requirements on the Planning and Construction of Coal-fired Power Plants (NDRC 2004)	New power plants and expansion projects should deploy dry-cooling technologies and dry/semidry flue gas desulfurization systems
Water Resources Assessment for the Development of Coal-Power Bases (China Ministry of Water Resources 2014)	■ Water use from the coal sector (including coal-fired power plants) must be within provincial quotas. ■ New coal projects are required to submit their feasibility reports to the Ministry of Water Resources and other bodies for approval.
Air Pollution Control Action Plan (China State Council 2013)	Prohibits new coal-fired power plants in the three most important metropolitan areas around Beijing, Shanghai, and Guangzhou (however, coal-fired plants may be driven westward to less-developed regions already burdened by water shortages).
Upgrade and Retrofit Plan for Coal-Fired Power Plants (NDRC 2014)	Continue to improve energy efficiency in the power sector by phasing out small, inefficient coal-fired power plants, which are also the most water-intensive.
China's Intended Nationally Determined Contributions (NDRC 2015)	China's greenhouse gas emissions will peak around 2030 and China will increase its share of non-fossil fuels in primary energy consumption to around 20 percent by the same year. A significant portion of new capacity will be wind and solar, which do not require water for operation.
The Action Plan for Water Pollution Prevention and Control (China State Council 2015)	Thermoelectric power plants in coastal regions should use seawater for cooling. By 2020, the power sector should meet an advanced level of water efficiency.

are clear winners in terms of water conservation and are likely to see rapid increase under China's low-carbon policies (NDRC 2015).

Electric power providers will need to find ways to deliver wind and solar power from utility-scale wind and solar farms that are in the remote west to economic centers in the east. In 2013, more than 16 Terawatt hours (or 11 percent) of China's wind output never made it to the grid (Li, Cai, and Qiao, et al. 2014).

New transmission projects and energy storage technologies can help match supplies of water-efficient fuels like wind and solar PV with demand. Projects like the West-to-East Electricity Transfer Project are creating eastbound transmission corridors using ultra-high-voltage technology (Gibson 2013). If energy from wind and solar can be stored, it matters less when and where the wind is blowing or the sun is shining. Energy storage is expected to be a market of $9 billion and 31 gigawatt hours in 2025 (Xie, Laslau, Frankel, and See 2015). China has piloted several storage technologies since 2010 and additional commercial partnerships can help further develop the market (Economic Daily News 2014). For example, Chinese battery manufacturer BYD, considered a leader in the domestic energy storage market, has formed a strategic alliance with ABB (a Swiss-based power and automation technologies company) and has also supplied the State Grid Corporation of China with the battery technology for a 36 megawatt hours energy storage station, the biggest in China.

Cooling technologies and power plant efficiencies will have an equally important role in reducing freshwater demands from the electric power sector. Even with rapid growth in wind and solar energy, a significant portion of China's future electricity needs will be met by coal-fired power plants (see Figure 8). Those plants, particularly in water-stressed regions, can look to technologies like dry cooling, which uses 70-80 percent less water than closed-loop cooling (China Electricity Council 2010; Sheng 2008). Similarly, electric power providers will upgrade and retrofit existing coal-fired power plants to increase their energy and water efficiency (NDRC 2014). Approximately 500 gigawatts of sub-critical capacity will be retrofitted to more efficient technologies by 2020, and 10 gigawatts of inefficient small coal-fired power generation capacity will be shut down during the same period.

Alternatives to freshwater. Instead of relying on freshwater for cooling, electric power providers are tapping alternatives like brackish water and seawater to provide reliable supply even during extreme droughts. According to the China State Oceanic Administration, 90 percent of thermoelectric plants in coastal cities have deployed seawater open-loop cooling systems (China State Oceanic Administration 2014).

Reclaimed water (treated municipal wastewater) is another valuable, reliable alternative to freshwater in water-stressed regions. The Huaneng combined heat and power project, for example, uses the effluent from a municipal wastewater plant in its closed-loop cooling system and avoids withdrawing 33,000 cubic meters of freshwater per day in water-stressed Beijing (China Huaneng Group 2010). As of 2014, 38 billion cubic meters of treated water was generated from municipal wastewater treatment plants across China (China Ministry of Environmental Protection 2015). Recently, China has announced a goal to reuse 20 percent of its municipal wastewater by 2020, up from today's less than 10 percent (China State Council 2015). The market for reclaimed wastewater is expected to amount to 85 billion RMB (about US$13.3 billion) in the next couple of years (E20 Research Institute 2015).

Electric power providers will need to partner with wastewater plant operators and treatment technology providers to scale reclaimed water as an alternative to freshwater cooling. Together, they can address challenges relating to the presence of nutrients and other contaminants in wastewater that can cause corrosion and biofouling on heat exchange surfaces.

***Thinking Differently:* Changing user demand.** A review of 20 combinations of power-generating technologies and cooling systems in China found that energy efficiency by end users is by far the most effective strategy for addressing water needs and reducing GHG emissions (Seligsohn et al. 2015). Electric power providers in China and elsewhere would be smart to partner with their own customers—to both reduce and shift energy demands—as part of efforts to reduce exposure to water risks.

What might electric power providers do with their customers that they cannot do alone?

- **Cut energy demand in half.** Electric power providers can test new business models and partner with industry coalitions that aim to increase customers' energy efficiency. For example, a new campaign on energy productivity for business growth is being developed by The Climate Group, in partnership with We Mean Business. It seeks to create a forum for sharing best practices and showcasing the leadership of companies making progress toward bold, public commitments on energy productivity (The Climate Group 2015). Electric power providers can encourage their customers to join this and similar partnerships to find the most cost-effective ways of meeting future energy demands while reducing strain on already stressed water resources.
- **Produce clean energy at point-of-use.** Electric power providers can leverage government support to invest in new models for distributed power generation and scale water-efficient energy sources like solar PV. Since 2012, the Chinese government issued at least 20 policies on distributed solar generation including a midterm development strategy, subsidy programs, grid interconnection service, funding, and pilot demonstration projects (Liang 2014). In 2014, 20 percent of China's new solar generation capacity was from distributed sources (China National Energy Administration 2015). Additional investment will be needed to hit China's overall goal of 35 gigawatts of installed solar by 2017 (China State Council 2013).
- **Create smart, responsive, resilient infrastructure.** To improve energy efficiency and better accommodate renewables, electric power providers can modernize transmission systems with smart-grid technologies. As part of the U.S.-China Climate Change Working Group Smart Grid initiative, U.S. industries have helped design a smart-grid demonstration project for China's Tianjin Eco-City, and the next step will place greater emphasis on industry engagement and technical assistance, aiming to expand institutional capacities for smart grids in the two countries (U.S. Department of State 2015).

WATER FOR ENERGY: UNCONVENTIONAL OIL AND GAS IN THE UNITED STATES

As the United States develops its domestic shale gas and tight oil reserves, it confronts tradeoffs between water and energy. The United States is the world's largest consumer of natural gas and oil and is rapidly developing new resources; it has the fifth-largest technically recoverable shale gas and second-largest tight oil resources (Reig et al. 2014). However, these resources can be extremely water intensive and are often found in areas where local water supplies are stressed. Estimates suggest that, by 2020, 60 percent of U.S. shale plays will be in regions with arid conditions or high or extremely high water stress.

This section looks at the example of the United States to illustrate:

- Water supply risks for unconventional oil and gas developers (and, indirectly, for industries relying on oil and gas)
- Opportunities to reduce exposure to water risks

Where Is Water Stress Creating Risks for Unconventional Oil and Gas Production?

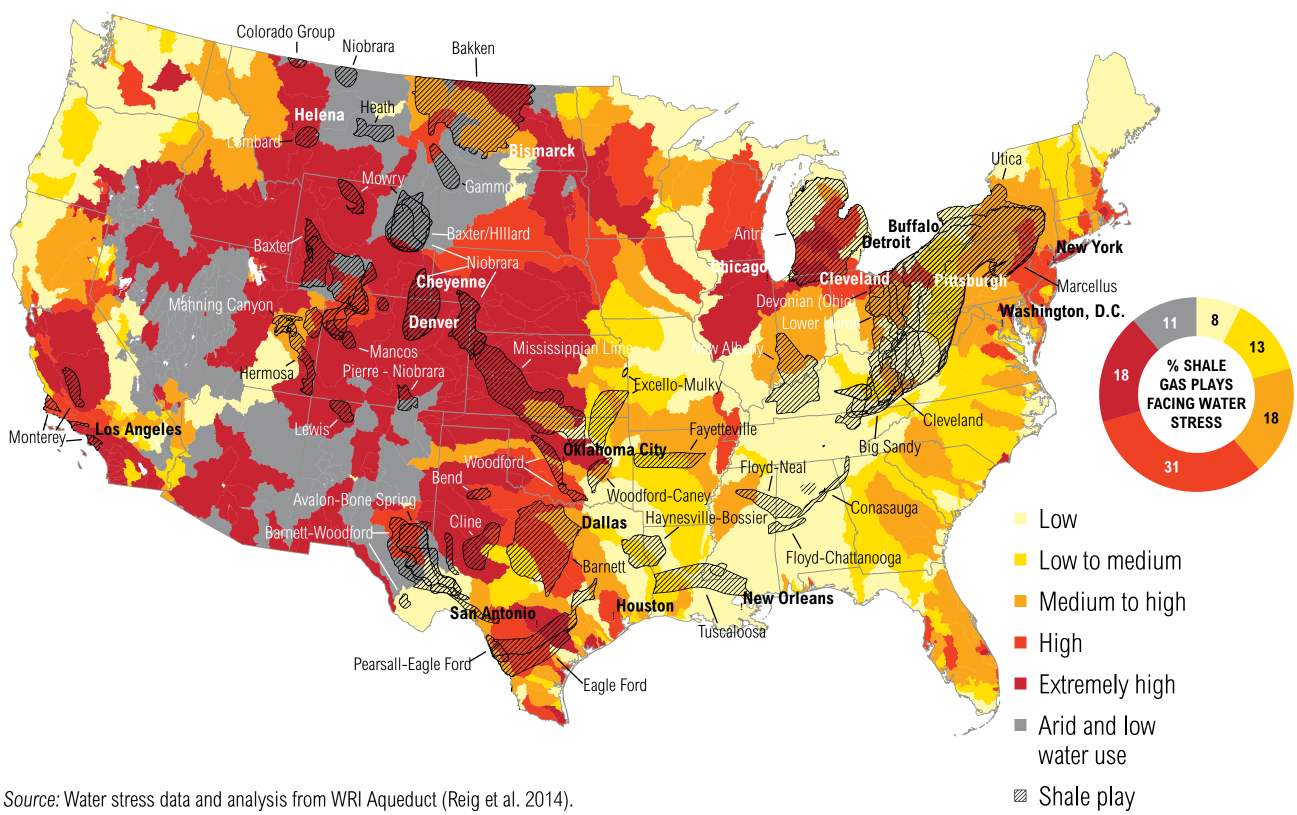
Most U.S. shale plays are in arid regions or regions with high or extremely high water stress, mainly in the western plains, California, and Texas (Figure 9).

Water plays a critical role in the development of unconventional oil and gas resources, which comprise shale gas, coalbed methane, heavy oil, tar sands, and other hydrocarbon reserves. In the United States, considerable reserves of shale gas and tight oil are contained in low-permeability shale formations and can be accessed only through hydraulic fracturing—using pressurized water or other fluids to fracture rocks to release the gas or oil.

U.S. unconventional oil and gas production has increased dramatically over the past 10 years (Sieminski 2014). Despite declines in oil and gas prices, recent data predict that U.S. natural gas production will rise by 1.9 percent in 2016 (EIA 2015). Further infrastructure development as well as high uncertainty in future oil prices indicate that unconventional sources are likely to remain an important element of oil and gas production in the United States for years to come.

The large water requirements for hydraulic fracturing can mean local water supply risks for oil and gas developers. Although hydraulic fracturing and drilling activities account for only one one

Figure 9 | **Sixty Percent of U.S. Shale Gas Plays are in Regions with Arid Conditions or High or Extremely High Water Stress**



Source: Water stress data and analysis from WRI Aqueduct (Reig et al. 2014).

thousandth of total U.S. water withdrawals, these withdrawals are highly localized and can constitute up to one third of total freshwater use in some U.S. counties (Reig et al. 2014). Between 10 and 75 percent of the water used in the fracturing process is returned to the surface as "produced water" through a process known as flowback; and because of its high chemical content, produced water must be disposed of or recycled appropriately (Reig et al. 2014). The 25 to 90 percent of water that doesn't return to the surface remains in the ground and cannot re-enter the hydrologic cycle. Removal of this much water can lead to groundwater depletion and increased competition for water resources with industrial, agricultural, and domestic users.

The growing development of unconventional oil and gas resources, particularly in areas of water stress, can pose increasing economic risks to developers. One risk is possible higher costs to withdraw water in water-stressed areas or to transport water long distances (Reig et al. 2014). For example, during a 2012 drought, Colorado municipalities charged oil and gas companies $1,000–$2,000 per acre-foot of water (farmers paid only $100 for the same quantity) (Reig et al. 2014).

Another risk is increasing or unexpected costs related to storing, shipping, treating, and disposing of produced water. Accidental leaks and spills during storage and shipping, or inadequate treatment prior to discharge, can lead to extra costs to clean up pollution or chemical contamination of land or freshwater resources (Hammer and VanBriessen 2012). Land application of either the wastewater or residual brines created during treatment can result in chemical contamination of local surface- and groundwater supplies (Hammer and VanBriessen 2012). Many states promote deep-well injection as an effective disposal technique. However, concerns about the risk of seismic activity or leakage into groundwater supplies have led other countries like the United Kingdom to prohibit such practices (DECC 2014).

Public concerns over groundwater depletion, growing competition for freshwater, and water quality degradation can also lead to reputational and regulatory business risks. These may delay projects, increase costs, and jeopardize companies' social or legal license to operate (Reig et al. 2014). They have also created liability concerns for operators, leading to dozens of lawsuits in the United States over the last several years (Arnold and Porter, LLP 2014).

What Are the Opportunities for Unconventional Oil And Gas Developers to Reduce Exposure to Water Risks?

To safely and economically develop unconventional oil and gas resources, developers will need to address the risks emerging in regions facing local water stress. They can use alternatives to freshwater and leverage new data and analytics to track, manage, and minimize water supply risks. These opportunities have the potential to solve many of the water-related issues in fracturing, but their implementation is challenging and will require new business models, technologies, and partnerships.

Alternatives to freshwater. Where freshwater is scarce, developers can look to alternatives, which include recycled wastewater, brackish water, and waterless fracturing technologies.

Wastewater treatment and recycling. Developers can recycle wastewater to ensure water availability and reduce wastewater disposal costs. Wastewater from hydraulic fracturing activities contains high levels of salts, sulfates, barium, strontium, and radium, and its composition varies greatly both between formations and over time after fracturing. After treatment, this water can be used to fracture another well, reducing freshwater requirements. However, fracturing operators disagree on the level of treatment necessary to prevent damage to fracturing wells (Rassenfoss 2011). Standardizing recycling practices requires further work, but offers the opportunity for a third-party operator to deploy a universal treatment service model. Industry-government partnerships can expedite recycling efforts. For instance, the Texas Railroad Commission, which regulates oil and gas production, began allowing the sale of wastewater among companies in 2013, and eliminated the permits previously required for onsite recycling (Freyman 2014). Stronger regulations on deep-well injection may also make alternative treatment options more cost competitive.


Several shale operations are recycling nearly 100 percent of their wastewater in multiple regions. They include QEP Resources in the Green River Basin of Wyoming, Apache Corporation in the Barnhart region of Texas, Newfield Exploration Company in Utah (CH2M Hill 2015), and at least two thirds of all operations in the Marcellus Shale (Rassenfoss 2011). Further reductions in energy requirements for treatment can bring treatment costs down, as will innovative service models for treating water only to the level required for its specific new purpose. Industry experts note that recycling provides economic benefit only for companies operating at a large scale or with a high density of wells, and cite logistics as a major barrier to cross-company wastewater partnerships. In addition, recycling will not be sufficient by itself as a water source; in the Marcellus Shale, where recycling is common, repurposed water meets only 10 to 30 percent of fracturing requirements (Scanlon, Reedy, and Nicot 2014). Still, recycling can be cost effective in areas where other disposal options are illegal or too expensive due to transportation costs, and should therefore be implemented wherever wastewater disposal is an environmental concern or liability (Rassenfoss 2011).

Brackish water. Brackish water aquifers are a mixture of freshwater and saltwater. They contain more total dissolved solids than freshwater, but offer an opportunity to minimize impacts on freshwater resources. Brackish water use is particularly well documented in the far west region of the Permian Basin in Texas, where it accounted for 80 percent of total water used for fracturing in 2011 (Nicot, Reedy, and Costley, et al. 2012). Although brackish water is currently too expensive except in areas of extreme drought, further research is likely to reduce the cost of brackish water applications elsewhere.

Unconventional oil and gas developers will need to find means of altering the chemical treatment of the source water based on the unique chemistry of both the brackish aquifer and the shale formation (Buchele 2013). Since the total dissolved solids of brackish water vary from 1,000 milligrams per liter to 35,000 milligrams per liter (Nicot et al. 2012), more research is necessary to assess the ideal quantity of salt to be added or removed to use these resources economically (Wythe 2013). In cross-sector water partnerships municipal and industrial wastewater could be used in fracturing to alleviate local water stress while saving energy, since the wastewater would not have to be treated to as high a standard as it would be for conventional disposal (Freyman 2014).

Waterless fracturing. Several technologies could help unconventional oil and gas developers eliminate water from the fracturing process entirely. Waterless fracturing techniques tend to require fluids more expensive than water, thus are only cost-effective when they lead to higher production rates or when water is costly or inaccessible. Unconventional oil and gas developers in water-scarce regions can support research and development, for example in partnerships with universities, to unlock the potential for environmental and economic benefits with options such as these:

- *Liquid petroleum gas and carbon-dioxide-based foams*, which have been in limited use as fracturing fluids for decades, but are cost effective only in specific applications or when water costs are high.
- *Liquid carbon dioxide*, recently used in commercial applications, which reduces formation damage and enhances gas recovery while also sequestering carbon dioxide and eliminating water use. However, its low density requires that fewer proppants be used than in water-based fracturing, which results in decreased fracture conductivity and slower production (Gandossi 2013).
- *Supercritical carbon dioxide*, which has a much higher density than regular carbon dioxide.

Early testing on its application as a fracturing fluid (Pei, Ling, and He, et al. 2015) shows it can increase the fracturing penetration rate, but more research is needed on pumping, transportation, and storage before it can be used widely (Rassenfoss 2011).

Data and analytics. Industry experts suggest that big data, analytics, enhanced transparency, and regulations will drive more interest in water monitoring and analysis. A 2015 survey by Accenture and Microsoft found that oil and gas industry professionals plan to spend more on big data, the industrial internet of things, and automation, despite low oil and gas prices (Accenture and Microsoft 2015).

Unconventional oil and gas developers can monitor, collect, and digitize data on local water sources to better understand water stress and manage exposure to risks. They can use sensors and remote monitoring technologies to record, improve, and report on the safety of their extraction and disposal processes. Data analysis that predicts water requirements based on well characteristics could also allow operators to plan more effectively for future water needs. Improved situational knowledge could help with internal planning and enable better coordination and collaboration with suppliers, partners, and regulators. Collaboration opportunities include cross-basin water infrastructure development, coordinated water supply management, sharing excess transportation capacity, and use of a common logistics management platform (Stark, Allingham, and Calder, et al. 2012). Water tracking from source to disposal lends itself to a cumulative approach for regulators because data gathered across a shale play can be aggregated to allow regulators to assess the combined environmental impacts of all fracturing operations (Stark et al. 2012).

More data on fracturing water use and its associated costs create opportunities for better analytics on water availability and expenses. Accessing source water is generally included in capital expenditures, whereas disposal of produced water is an operating cost. Unconventional oil and gas developers can use software to track water expenses and improve water transportation and logistics management (Stark et al. 2012).

***Thinking Differently:* Pricing carbon and valuing water.** The costs of oil, gas, and water are likely to increase as populations and resource demands grow. Unconventional oil and gas developers can test future investments by pricing expected carbon (or more broadly, GHG emissions) costs and assessing the value of water as part of internal financial assessments and decisions.

Pricing carbon to prepare for future costs and evaluate investment risks is an increasingly common business practice. More than 1,000 companies report that they are pricing carbon internally, or plan to within the next few years (CDP 2015). Some are doing it in preparation to comply with new regulatory requirements that will restrict GHG emissions. Others are doing it to prepare for changes and costs they expect in their key markets and value chains (i.e., increasing costs for carbon-intensive energy and other products). Still others are pricing carbon because of pressure from customers or investors. In the case of unconventional oil and gas development, a price on carbon can be helpful in valuing potential costs related to methane emissions in current operations or customer demand in future markets. Many major oil and gas developers—including Statoil, Shell, and others—are already pricing carbon. Others can draw lessons from current experience and join carbon pricing leadership initiatives to gain further insights.[7]

Valuing water is more complex and there is less experience with the practice to date, but emerging cases and frameworks can inform such efforts.[8] Importantly, water costs will not reflect the full value of investments that help avoid supply disruptions in times of drought or reputational damage and regulatory costs related to water quality impacts or community conflicts. Experience shows there is a strong case for a broader water valuation. A review of 21 business water-related valuation studies highlighted five reasons a business should assess the value of water: to enhance decisionmaking; maintain and enhance revenues; reduce costs; manage risks; and enhance their reputation (WBCSD 2012). Unconventional oil and gas developers operating, or considering operating in water-stressed areas, should consider assessing and incorporating the full value of water to inform their investments.

CONCLUSION

Innovation at the water-energy nexus involves thinking differently about how industries meet their customers' water and energy needs. Overcoming today's barriers will require new ideas, approaches, and collaboration. Instead of trying to expand the supply of limited freshwater and fossil fuel resources, companies can find opportunity in reducing demand and scaling alternatives.

This report asked two questions:

- Where are companies facing risks at the water-energy nexus?
- What are the opportunities for companies to reduce exposure to these risks and meet customers' needs in tomorrow's markets?

Derivations of those questions were examined for industries in three regions, which provided illustrations—and ideas—for potential solutions. Because of their scale and circumstances these industries and regions are among the first to confront risks at the water-energy nexus. MENA is among the driest regions on the planet. China claims the world's largest thermoelectric power fleet. The United States is the largest consumer and now a fast-growing producer of oil and gas. Their examples can help answer similar questions in other regions.

Increasing the production of one resource (energy or water) created risks related to ensuring a reliable, affordable supply of the other. Water providers in MENA, electric power providers in China, and unconventional oil and gas developers in the United States are all working to meet growing demand. Each faces costs related to their reliance on finite and stressed water supplies.

Advanced technologies that increase water and energy efficiency help industries reduce exposure to water and energy supply risks. Industries have opportunities to support emerging research on energy recovery, evaluate and prioritize water-efficient cooling technologies, and even harness big data and analytics to increase the efficiency of their operations.

To further reduce exposure to future water and energy supply risks, industries in the three regions are exploring innovative new technologies, business models, and partnerships that can shift demand to alternative water and energy resources. Wastewater reuse, brackish water aquifers, and seawater have emerged as promising alternative water sources in each region. Wind and solar emerged as water-efficient, clean power sources for electric power and water providers. Industries have opportunities to invest in new infrastructure to bring remote water or energy resources to demand centers. Or, they can test and prove new distributed generation models that produce clean energy or clean water at the customers' sites.

Some solutions require more experience, information, or RD&D. Continued technical and commercial development will be important, particularly for solutions that hold long-term

promise, like CSP for desalination. In those cases, industries have the opportunity to partner with universities, technical or commercial partners, or even service providers. Collaborations can help test innovative technologies, bring energy costs down, or prove new water service models. Collaborations may also focus on collecting, tracking, and making sense of data from monitoring water quality, aggregating and projecting water expenses, or mapping brackish aquifers.

Finally, each section of this report challenged the industries and regions to think boldly and differently. Water providers and others can involve women in managing and planning for water supply and demand. Innovations and high ambition can address energy end-use and scale distributed generation and smart electric power infrastructure to provide win-win solutions for energy and water risks. Finally, companies operating at the water-energy nexus can stress test the long-term viability of investments relying on freshwater and fossil fuels by pricing carbon and valuing water.

The shared nature of water and energy resources means that no single company, industry, country, or even region, can ensure access to clean energy and clean water on its own (World Bank 2015b). As industries and companies around the world confront risks at the water-energy nexus, they can draw inspiration from the examples offered here. The common lessons can be summarized in a checklist:

- **Acknowledge emerging risks to supply, but don't overlook solutions that address demand.** Why try to squeeze more out of limited freshwater supplies when end-use efficiencies offer water-energy "win wins"?
- **Take full advantage of water reuse and energy recovery.** Why waste valuable water and energy resources when they can be put to use reducing costs and supply risks?
- **Shift demand to alternative water options and clean energy resources.** Why rely only on freshwater and fossil fuels in a world of increasing demand and competition for those sources?
- **Create new partnerships and business models.** Collaboration and innovation are needed to commercialize the technologies and services that are not viable today, but will be essential for reducing exposure to supply risks in tomorrow's markets.

It is a simple list, but continued efforts to follow it will help overcome today's barriers, address tomorrow's risks, and achieve 2030's Sustainable Development Goals at the water-energy nexus.

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ENDNOTES

1. This report focuses on the water-energy nexus, but the concept links to other resources, such as food (water-energy-food nexus), or other global challenges, such as climate change (water-energy-climate nexus). This report does not discuss these links or risks and solutions for other important industries, such as agriculture. For additional discussion, see for example, FAO 2014 and World Economic Forum 2011.

2. Renewable water availability and water gap projections are taken from World Bank 2012, which draws on previous population estimates for 2050. Other population estimates use more recent data from World Bank 2015a.

3. Energy measures noted in this report include tera-, giga-, mega-, and kilo- watts. In terms of magnitude, 1 terawatt (TW) is equal to 1,000 gigawatts (GW); 1 GW is equal to 1,000 megawatts (MW); 1 MW is equal to 1,000 kilowatts (kW). Measures are also noted in terms of energy transmitted or used per a period of time, such as kilowatt-hours or kilowatt hours.

4. By convention, water withdrawal of hydroelectric power plants is often considered zero. Water consumption of hydropower is site-specific and largely due to evaporation from reservoirs.

5. Coal-fired power generation also presents risks for air and water quality, as well as contributing significant greenhouse gas emissions, which further exacerbate climate change risks.

6. For a detailed breakdown of water withdrawal and consumption by fuel and cooling technology, see Macknick, Newmark, and Heath, et al., 2015.

7. See for example Metzger, Park, and Gallagher 2015; and additional resources at www.caringforclimate.org/carbon-pricing and www.carbonpricingleadership.org.

8. See for example WBCSD 2012; WWF and IFC 2015; and additional resources at www.wri.org/aqueduct and www.wri.org/our-work/topics/economics.

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ABOUT WRI

World Resources Institute is a global research organization that turns big ideas into action at the nexus of environment, economic opportunity and human well-being.

Our Challenge

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our Vision

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our Approach

COUNT IT

We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT

We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT

We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.

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