

THE BOTTOM LINE

Population growth and economic development, aggravated by climate change, will increase pressure on energy and water resources. Integrated planning can make the most of these two essential and scarce resources. Thirsty Energy, a World Bank initiative, helps countries address these issues and ensure sustainable development of both resources.

Thirsty Energy: Understanding the Linkages between Energy and Water

Why is this issue important?

Water and energy are equally vital and inextricably linked, and integrated planning is needed to maximize both

Both water and energy are essential for economic activity and to sustain life. And both are scarce. Some 780 million of the world's people lack access to improved water, while 2.5 billion, more than a third of the world's population, do not have basic sanitation. Another third (2.8 billion people) lives in areas of high water stress (WWAP 2012). On the energy side, more than 1.3 billion people around the world have no access to electricity, and 1.2 billion have unreliable access (IEA 2012).

Population growth and economic development, aggravated by climate change, will increase pressure on energy and water resources. Integrated planning can make the most of these two essential and scarce resources. Energy (mainly electricity) is needed to pump, treat, transport, and desalinate water. Conversely, significant amounts of water are needed in almost all energy generation processes. Water is used to generate electricity in hydropower plants, of course, but many people are unaware that almost all thermal power plants (coal, nuclear, solar-thermal, geothermal, biomass, and natural gas combined-cycle) require large amounts of water, especially for cooling purposes. Water is also needed to extract, process, and generate fuels.

This note focuses on the water needs of the power sector.

Do power plants need all that much water?

Thermal power plants need water for cooling, but efficient plants and the right cooling system save water

Largely because of their cooling needs, thermoelectric power plants account for about 40 percent of the freshwater withdrawn each year in the United States and Europe—as much as the agriculture sector (USGS 2005; Rubbelke and Voge 2011).

About 80 percent of the world's electricity is generated in thermal power plants (IEA 2013). Most thermal power plants heat water to produce steam to drive the turbines to produce electricity.¹ The water is heated using various energy sources (coal, oil, natural gas, uranium, solar energy, biomass, geothermal energy) depending on the type of power plant, but the principle is the same. After passing through the turbine, the steam is cooled, usually with water drawn from a river, lake, or ocean and condensed to start the cycle again (figure 1).

Because most of the water needed in thermal power plants is used for cooling,² the amount of water withdrawn and consumed by



Anna Delgado is a technical specialist in water and energy in the World Bank's Global Water Practice.



Diego J. Rodriguez is a senior economist in the in the Global Water Practice.

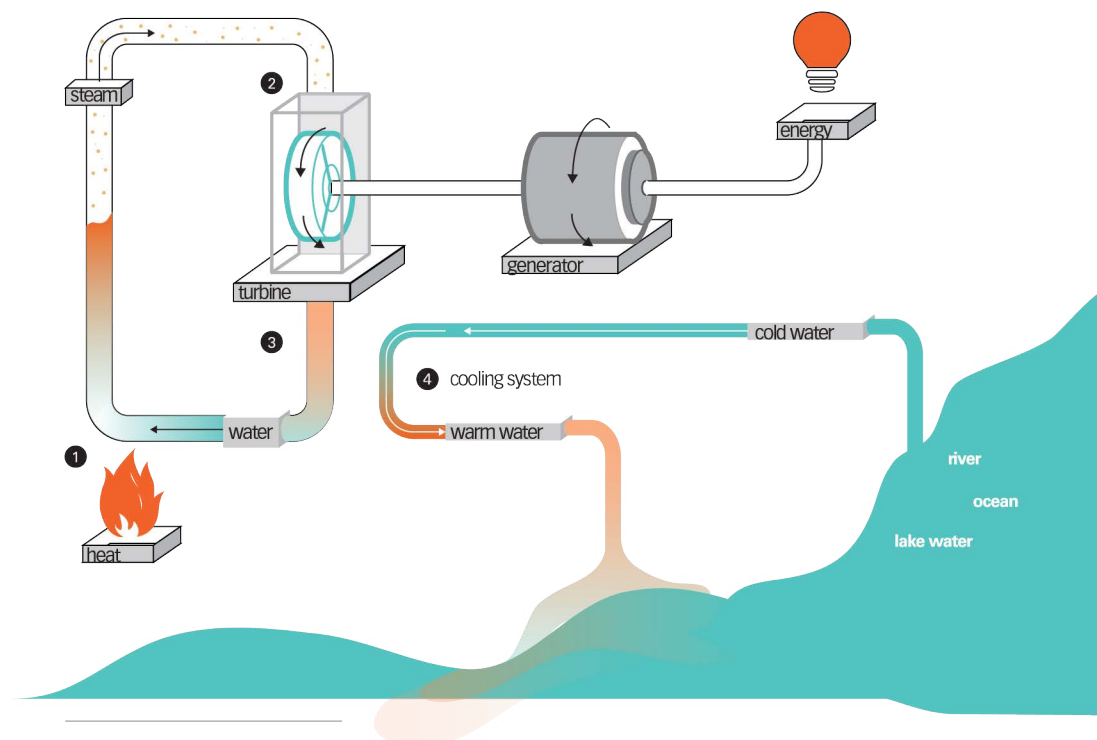


Antonia A. Sohns is a water and energy analyst in the Global Water Practice.

¹ Open-cycle power plants (mainly used as peak power plants) do not use the steam cycle to turn turbines and thus do not require water for cooling.

² The other processes for which water is required include the steam cycle, ash handling, and flue-gas desulfurization, among others. Although these processes consume relatively little water, their effluents contain pollutants and should be treated before being returned to the water source. From a plant-level economic standpoint, therefore, such processes can incur very significant costs related to wastewater treatment.

Figure 1. The steam cycle in a thermal power plant



Source: Authors.

“Largely because of their cooling needs, thermoelectric power plants account for about 40 percent of the freshwater withdrawn each year in the United States and Europe—as much as the agriculture sector.”

















the power plant depends chiefly on the type of cooling system used (Rodriguez and others 2013).

Once-through cooling, the simplest and cheapest system, requires large amounts of water but consumes a small fraction of it. The water is withdrawn from the water source and run once through the power plant (hence the name) to cool steam. The water is then discharged back into the source a few degrees warmer, which can cause thermal pollution. The withdrawal of large quantities of water can be harmful to fish and other aquatic organisms. Once-through cooling systems are more susceptible than others to drought or extreme heat (van Vliet and others 2012).

- **Closed-loop systems** are characterized by cooling towers that often are mistaken for nuclear power plants. Closed-loop systems withdraw much less water but consume most of it through evaporation. These cooling systems are more complex and expensive than once-through systems, but since they withdraw less water, they have fewer environmental effects and are less susceptible to drought.
- **Dry cooling systems** use air instead of water to cool steam. Their high cost and negative impact on plant efficiency limit their use.
- **Hybrid cooling systems** combine wet and dry cooling approaches.

"The system employed by the power plant affects power plant efficiency, capital and operating costs, water consumption, water withdrawal, and environmental impacts. Tradeoffs must be evaluated case by case, taking into consideration regional and ambient conditions and existing regulations."

Figure 2. Tradeoffs between different types of cooling systems

main types of cooling systems	use	water withdrawal	water consumption	efficiency	cost	environmental impact
once through 	 water				\$ small	 bad
cooling towers 	 water				\$\$ medium	 moderate
dry cooling 	 air	0	0		\$\$\$ high	 none

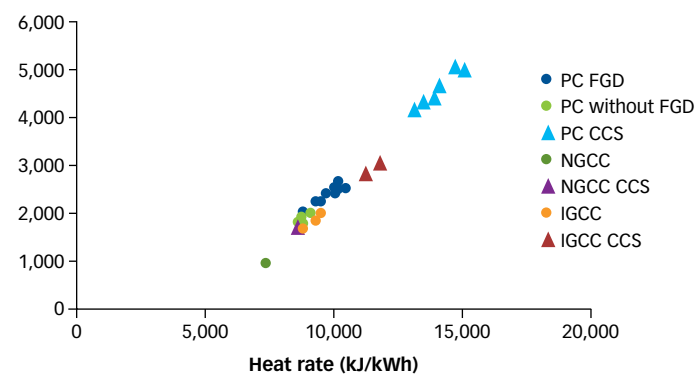
Source: Authors.

The system employed by the power plant affects power plant efficiency, capital and operating costs, water consumption, water withdrawal, and environmental impacts. Figure 2 illustrates the tradeoffs between various systems. Those tradeoffs must be evaluated case by case, taking into consideration regional and ambient conditions and existing regulations.

Among plants with the same type of cooling system, the amount of cooling water withdrawn and consumed is determined largely by the plants' efficiency (Delgado 2012). Figure 3 illustrates the correlation between power plants' water use and their efficiency ("heat rate").

Because a new solar thermal power plant equipped with a given cooling system is still less efficient today than a new coal power plant equipped with the same system, it will require more water. However, it will require significantly less water than an old and inefficient coal power plant. This is because as power plants

Figure 3. Correlation between water use and efficiency in thermal power plants

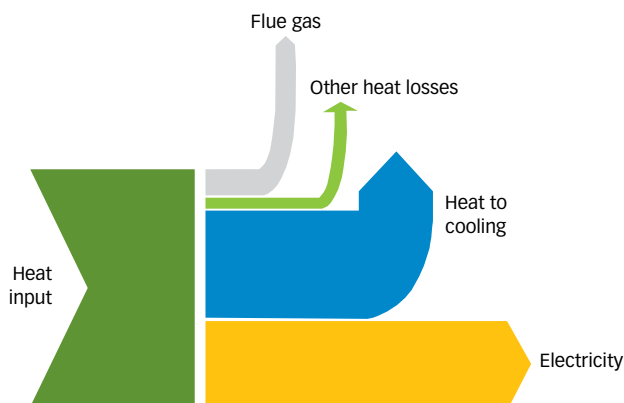


Source: Delgado 2012.

PC = pulverized coal; FGD = flue-gas desulfurization; CCS = carbon capture and storage; NGCC = natural gas combined cycle; IGCC = integrated gasification combined cycle.

“To compare power plants in terms of their water needs without specifying the type of cooling system they use and their efficiency is very misleading, but this has not stopped the media from reporting, for example, that coal power plants require more water than nuclear plants and less than solar thermal plants.”

Figure 4. Heat balance of a thermal power plant



Source: Authors.

become more efficient, less “waste heat” remains to be dissipated after driving the turbines. This means that the cooling requirements per unit of electricity produced diminish. In figure 4, the yellow arrow becomes bigger and the blue arrow smaller.

To compare power plants in terms of their water needs without specifying the type of cooling system they use and their efficiency is very misleading, but this has not stopped the media from reporting, for example, that coal power plants require more water than nuclear plants and less than solar thermal plants.

What about other types of plants?

Other power generation technologies—hydropower, wind energy, and solar photovoltaic (PV)—vary in their water needs

Because hydropower plants use the energy of moving water to turn turbines and generate electricity, hydropower planners have been aware of the linkages between energy and water for a long time. In hydropower plants, water loss is due to evaporation from dammed water upstream from the plant. Evaporation losses vary greatly depending on site location, design, and operation. So-called run-of-river hydropower plants, which store no water, have evaporative

losses near zero. (However, unlike dammed hydropower, a run-of-the-river site cannot be used to generate peak loads or during dry seasons when the flow of the river drops.) Except for losses to evaporation, the water that passes through hydropower plants can be used downstream for other purposes, such as irrigation and urban water supply. Hydropower dams can even increase water availability for downstream users when that water is needed the most, as during periods of drought.

In a world of severe energy shortages and increasing water variability, hydropower dams and their multipurpose water infrastructure will play an expanding role in providing clean energy and in allocating scarce water resources. The careful planning and equitable use of sustainable power and water infrastructure in river basins will be critical in meeting the challenge posed by the linkages between energy and water.

Wind turbines require no water for their operation. Solar PV systems require minimal quantities of water for washing the solar panels (to maintain efficiency), but because most such systems are located in arid places, the water required could be scarce.

Hydropower, wind, and solar energy plants will not replace thermal plants in the near future. Hydropower is location-specific—that is, only certain areas of the world have substantial potential. Wind and solar energy are intermittent and present challenges of integration into the grid. Until electricity storage becomes practical on a grid scale, thermal power plants will be needed to generate dispatchable power (except in some cases where hydropower is plentiful).

What are the challenges?

Water–energy risks will grow over time, but the impacts are already being felt

The private energy sector has already recognized the inherent tension between energy and water resources. In 2012, General Electric’s director of global strategy and planning stated that water scarcity could rule out expansion of coal power plants in China and India (Pearson 2012). A 2013 report on the water risks facing the private sector found that, of the companies surveyed, 82 percent of energy and 73 percent of power utility companies believe that water presents a substantial risk to business operations. Moreover, 59

"In a world of severe energy shortages and increasing water variability, hydropower dams and their multipurpose water infrastructure will play an expanding role in providing clean energy and in allocating scarce water resources."

percent and 67 percent, respectively, had experienced water-related business impacts in the past five years (CDP 2013). The 2012 UN Water Report, which surveyed more than 125 countries, found that nearly half said that the importance of water for energy was high or very high, compared with 9 percent that said that it was not a problem. The World Economic Forum has listed water scarcity as one of the three global systemic risks of highest concern (WEF 2014).

Given the growth of many developing countries we can anticipate that problems at the nexus of water and energy will increase as population, economic growth, and climate change intensify competition for water resources. In the United States, France, and India, power plants have down owing to the unavailability of water for cooling or to its high temperature (U.S. Department of Energy 2013; Kanter 2007; NDTV 2013). Projects to build thermal power plants have been called into question because of their impact on water resources (Woody 2009). More frequent and longer droughts are challenging the hydropower capacity of some countries (Sirilal and Aneez 2012; Stanway 2011; Stauffer 2013).

What are our options?

The interdependencies of water and energy must be better understood and translated into policies and plans

There are ways to reduce the water requirements of the power sector—among them fostering the use of alternative cooling systems such as dry cooling (Maulbetsch 2004); expanding the role of wind and solar PV energy, which require little or no water for their operation; using alternative water sources for cooling, such as municipal waste water (U.S. Department of Energy 2009); exploring the use of multipurpose dams; improving power plant efficiency; and reusing waste heat (for example, to heat buildings or homes).

At a regional level, there is much to be gained by bringing together two sectors that traditionally have been planned and managed separately, understanding the trade-offs they present, and seeking integrated and efficient solutions consistent with sustainable development.

To make informed decisions and avoid irreversible consequences, it will be crucial to improve our understanding of water and

energy interdependencies. In January 2014 the World Bank launched the Thirsty Energy initiative, the aim of which is to help countries address their water and energy challenges by:

- Identifying synergies and quantifying trade-offs between energy development and water use
- Piloting cross-sectoral planning to ensure sustainability of energy and water investments
- Designing assessment tools and management frameworks to help governments coordinate decision-making and to mainstream water requirements into energy planning.

More information on the initiative can be found at: www.worldbank.org/thirstyenergy.

References

- CDP (Carbon Disclosure Project). 2013. "Moving beyond business as usual: A need for a step change in water risk management—CDP Global Water Report 2013." London. <https://www.cdp.net/CDPResults/CDP-Global-Water-Report-2013.pdf>.
- Delgado, A. 2012. "Water Footprint of Electric Power Generation: Modeling its use and analyzing options for a water-scarce future." MS thesis, Massachusetts Institute of Technology, Cambridge, MA, USA. https://sequestration.mit.edu/pdf/AnnaDelgado_Thesis_June2012.pdf.
- IEA (International Energy Agency). 2012. *World Energy Outlook 2012*. Paris.
- . 2013. *World Energy Outlook 2013*. Paris.
- Kanter, J. 2007. "Climate change puts nuclear energy into hot water." *New York Times*, May 20. <http://www.nytimes.com/2007/05/20/health/20iht-nuke.1.5788480.html?pagewanted=all>.
- Maulbetsch, J. 2004. "Comparison of Alternate Cooling Technologies for U.S. Power Plants: Economic, Environmental, and Other Tradeoffs." Electric Power Research Institute, Palo Alto, CA, USA.
- NDTV. 2013. "Maharashtra: Parli power plant shuts down after severe water crisis." February 17. <http://www.ndtv.com/article/india/maharashtra-parli-power-plant-shuts-down-after-severe-water-crisis-331952>.

MAKE FURTHER CONNECTIONS

Live Wire 2014/18.
“Exploiting Market-Based Mechanisms to Meet Utilities’ Energy Efficiency Obligations,” by Jonathan Sinton and Joeri de Wit.

Live Wire 2014/26. “Doubling the Share of Renewable Energy in the Global Energy Mix,” by Gabriela Elizondo Azuela and Irina Bushueva.

Live Wire 2014/36.
“Supporting Hydropower in the Developing World: An Overview of World Bank Group Engagement,” by William Rex, Julia Bucknall, Vivien Foster, Rikard Liden, and Kimberly Lyon.

Live Wire 2015/38.
“Integrating Variable Renewable Energy into Power System Operations,” by Thomas Nikolakakis and Debabrata Chatopadhyay.

- Pearson, Natalie Obiko. 2012. “Asia Risks Water Scarcity Amid Coal-Fired Power Embrace.” Bloomberg Business. <http://www.bloomberg.com/news/articles/2012-09-09/asian-water-scarcity-risked-as-coal-fired-power-embraced>.
- Rodriguez, Diego J., Anna Delgado, Pat DeLaquil, and Antonia Sohns. 2013. “Thirsty Energy.” World Bank, Washington DC. <https://openknowledge.worldbank.org/handle/10986/16536>.
- Rubbelke, D., and S. Vogele. 2011. “Impacts of climate change on European critical infrastructures: The case of the power sector.” *Environmental Science Policy* 14: 53–63.
- Sirilal, R., and Shihar Aneez. 2012. “Sri Lanka extends daily power cut as Chinese plant fails again.” Reuters, August 13. <http://in.reuters.com/article/2012/08/13/srilanka-power-idINDEE87C0AC20120813>.
- Stanway, D. 2011. Reuters, “China power crunch to worsen as drought slashes hydro.” Reuters, May 25. <http://www.reuters.com/article/2011/05/25/us-china-drought-hydropower-idUSTRE74O1BK20110525>.
- Stauffer, C. 2013. “Worst drought in decades hits Brazil’s Northeast.” Reuters, January 4. <http://www.reuters.com/article/2013/01/04/us-brazil-drought-idUSBRE9030HM20130104>.
- UN Water. 2012. “Status Report on The Application of Integrated Approaches to Water Resources Management.” http://www.un.org/waterforlifedecade/pdf/un_water_status_report_2012.pdf.
- U.S. Department of Energy. 2009. “Use of Non-Traditional Water for Power Plant Applications: An Overview of DOE/NETL R&D Efforts.” <http://www.netl.doe.gov/File%20Library/Research/Coal/ewr/water/Use-of-Nontraditional-Water-for-Power-Plant-Applications.pdf>.
- . 2013. “U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather.” <http://energy.gov/sites/prod/files/2013/07/f2/20130710-Energy-Sector-Vulnerabilities-Report.pdf>.
- USGS (United States Geological Survey). 2005. “Estimated Use of Water in the United States in 2005.” <http://pubs.usgs.gov/circ/1344/pdf/c1344.pdf>.
- van Vliet, M., J. Yearsley, F. Ludwig, S. Vögele, D. Lettenmaier, and P. Kabat. 2012. “Vulnerability of US and European electricity supply to climate change,” *Nature Climate Change* 9: 676–681.
- Woody, T. 2009. “Alternative Energy Projects Stumble on a Need for Water.” *New York Times*, September 29. <http://www.nytimes.com/2009/09/30/business/energy-environment/30water.html?pagewanted=1&r=2>.
- WWAP (World Water Assessment Program). 2012. “The United Nations World Water Development Report 4.” UNESCO, Paris.
- WEF (World Economic Forum). 2014. “Global Risks 2014. Ninth Edition.” http://www3.weforum.org/docs/WEF_GlobalRisks_Report_2014.pdf.

The authors thank Rikard Liden, senior hydropower specialist in the World Bank Group, for his contributions to the hydropower section.

Get Connected to Live Wire

"Live Wire is designed for practitioners inside and outside the Bank. It is a resource to share with clients and counterparts."

The *Live Wire* series of online knowledge notes is an initiative of the World Bank Group's Energy and Extractives Global Practice, reflecting the emphasis on knowledge management and solutions-oriented knowledge that is emerging from the ongoing change process within the Bank Group.

Each *Live Wire* delivers, in 3–6 attractive, highly readable pages, knowledge that is immediately relevant to front-line practitioners.

Live Wires take a variety of forms:

- **Topic briefs** offer technical knowledge on key issues in energy and extractives
- **Case studies** highlight lessons from experiences in implementation
- **Global trends** provide analytical overviews of key energy and extractives data
- **Bank views** portray the Bank Group's activities in the energy and extractives sectors
- **Private eyes** present a private sector perspective on topical issues in the field

Each *Live Wire* will be peer-reviewed by seasoned practitioners in the Bank. Once a year, the Energy and Extractives Global Practice takes stock of all notes that appeared, reviewing their quality and identifying priority areas to be covered in the following year's pipeline.

Live Wires are designed for easy reading on the screen and for downloading and self-printing in color or black and white.

For World Bank employees: Professional printing can also be undertaken on a customized basis for specific events or occasions by contacting GSDPM Customer Service Center at (202) 458-7479, or sending a written request to cgdsdp@worldbank.org.

Printing & Multimedia Services
General Services



Please visit our Live Wire web page for updates:
<http://www.worldbank.org/energy/livewire>

OPEN KNOWLEDGE REPOSITORY



Do you have something to say? Say it in *Live Wire*!

Live Wire offers prospective authors a support system to make sharing your knowledge as easy as possible:

- Trained writers among our staff will be assigned upon request to draft *Live Wire* stories with staff active in operations.
- A professional series editor ensures that the writing is punchy and accessible.
- A professional graphic designer assures that the final product looks great—a feather in your cap!

Live Wire aims to raise the profile of operational staff wherever they are based; those with hands-on knowledge to share. That's your payoff! It's a chance to model good "knowledge citizenship" and participate in the ongoing change process at the Bank, where knowledge management is becoming everybody's business.

If you can't spare the time to contribute to *Live Wire*, but have an idea for a topic, or case we should cover, let us know!

We welcome your ideas through any of the following channels:

Via the Communities of Practice in which you are active

By participating in the Energy and Extractives Global Practice's annual *Live Wire* series review meeting

By communicating directly
with the team (contact
Morgan Bazilian, mbazilian@
worldbank.org)

