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WORKING PAPER

PARCHED POWER: WATER DEMANDS, RISKS, AND OPPORTUNITIES FOR INDIA'S POWER SECTOR

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EXECUTIVE SUMMARY

Highlights

- India's thermal power sector is very dependent on water and has been suffering from water shortages, losing a substantial part of its generation growth every year since 2013. Most of the country's existing plants are likely to experience an increased level of water competition by 2030.
- Fourteen of India's top 20 largest thermal power utility companies have experienced water shortage–related disruptions at least once between 2013 and 2016, losing more than $1.4 billion in total potential revenue.
- Water consumption from India's thermal power generation rose steadily every year between 2011 and 2016 but would stay below its 2016 level by 2027 if the country's most ambitious renewable goals are successfully achieved and the notified stringent water regulations implemented.
- This study provides a first-cut assessment of the water risks associated with India's thermal power sector, leveraging a new plant-level database with information on cooling technology, source water type, water withdrawal and consumption, and actual generation for all thermal utilities in India.
- The Ministry of Power, Government of India, should mandate that power plants monitor and disclose water withdrawal and discharge data, create guidelines and policy incentives to drive better performance in managing water use and risks, and prioritize solar photovoltaic (PV) and wind projects when possible.

CONTENTS

Working Papers contain preliminary research, analysis, findings, and recommendations. They are circulated to stimulate timely discussion and critical feedback, and to influence ongoing debate on emerging issues. Working papers may eventually be published in another form and their content may be revised.

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Context

India's demand for water will continue to grow, despite being an already water-stressed nation. Freshwater resources are already scarce in most parts of India (Shiao et al. 2015). As India's economy is projected to double by 2030 (PwC 2017), the country's water demand is also expected to grow significantly across sectors (CWC 2015).

The power sector in India is very dependent on water and has been suffering from droughts and water shortages. More than 80 percent of India's electricity is generated from thermal (fossil fuel, biomass, nuclear, and concentrated solar) power plants (CEA 2017) that rely significantly on water for cooling. Another 10 percent of electricity is generated from hydroelectric plants, which depend on water completely. Thermal power plants have been forced to shut down due to inaccessibility of cooling water, losing tens of terawatt-hours of electricity generation in recent years (Luo 2017).

This paper aims to help decision-makers understand the magnitude of water issues for the thermal power sector in India with quantitative evidence. There is a significant data gap in power plant water use in India. The authors used data science techniques and innovative methodologies and developed a comprehensive plant-level geodatabase on water withdrawal and consumption for India's thermal power sector, making a first-cut attempt to fill the data gap. Combined with information on power generation, water risks, and future projections of energy and water demand, this paper quantifies the Indian thermal power sector's water demand, assesses its exposure to water stress, and evaluates opportunities for reducing water requirements while supporting power growth for the future.

Box ES-1 | **Definitions of Water Withdrawal and Consumption**

WATER WITHDRAWAL: the total amount of water that is diverted from a water source (e.g., surface water, groundwater) for use.

WATER CONSUMPTION: the portion of water withdrawal that is not returned to the original water source after being withdrawn.

Source: Reig (2013).

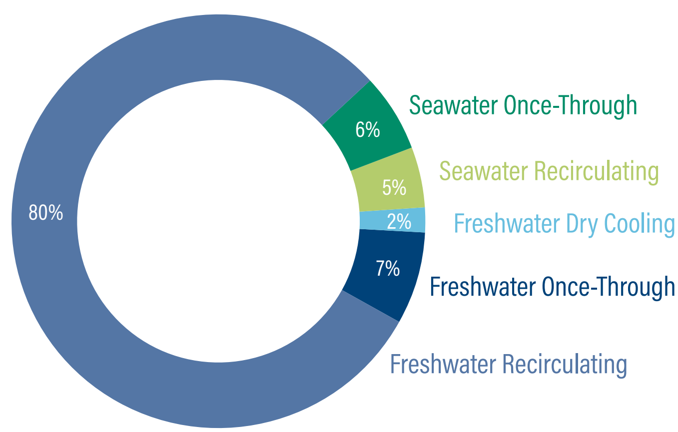
Key Findings

Almost 90 percent of India's thermal power generation depends on freshwater for cooling. In 2016, thermal (fossil and nuclear) electricity accounted for more than 83 percent of India's total utility power generation (CEA 2017). More than 80 percent of the total thermal generation was cooled by freshwater recirculating systems, as shown in Figure ES-1. Freshwater once-through systems are the second–most common cooling technology in India, accounting for about 7 percent of total thermal generation in 2016.

Freshwater consumption from Indian thermal utilities increased by 43 percent from 2011 to 2016, while withdrawals stayed fairly stable. The increase in consumption is due to the steady growth in electricity generation, as illustrated in Figure ES-2, and an increased share of electricity generated by plants with recirculating cooling systems. Stable water withdrawals during the period reflect that no new freshwater once-through cooled power plants were built after 2011. Although water withdrawals have not increased, the substantial increase in freshwater consumption means there is reduced freshwater available to other sectors.

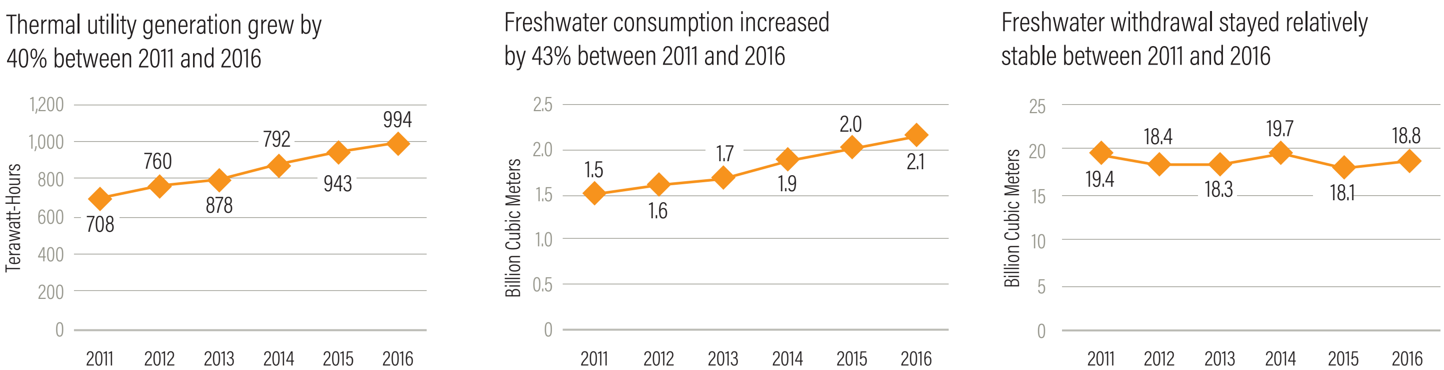
Figure ES-1 | **India's Thermal Utility Power Generation Distribution by Water Source and Cooling Technology**

In 2016, almost 90% of India's thermal utility power generation used freshwater for cooling



Source: WRI authors

Figure ES-2 | **India's Annual Thermal Utility Generation, Freshwater Consumption, and Withdrawal between 2011 and 2016**



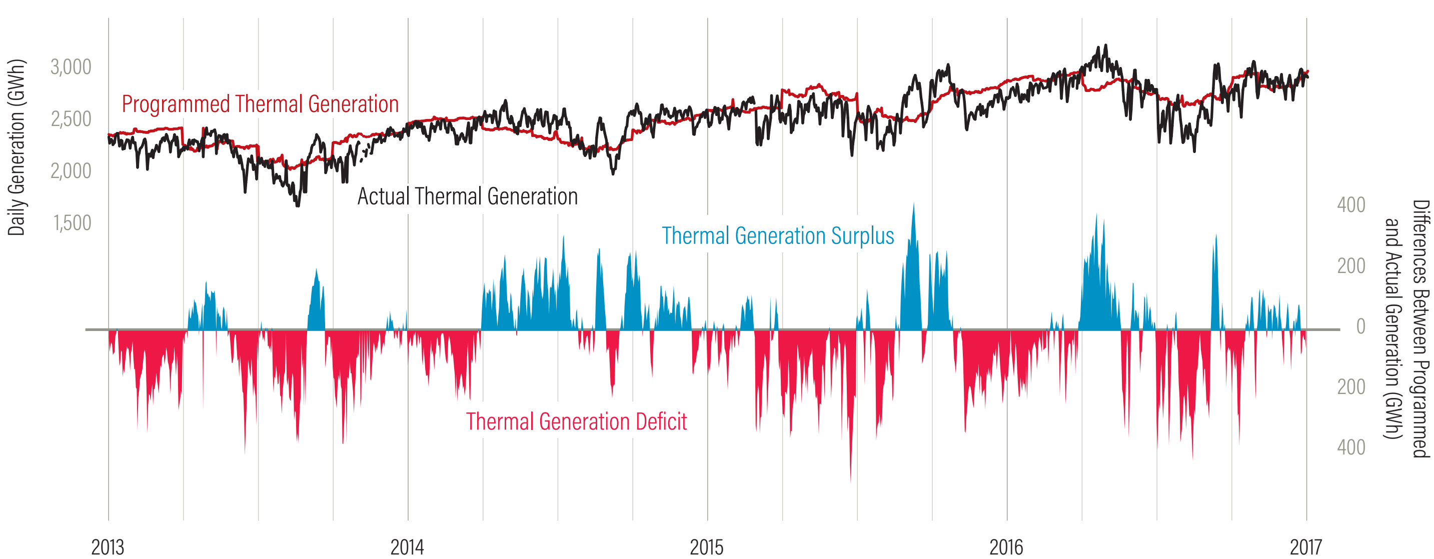
Sources: WRI authors; CEA (2017)

India lost about 14 terawatt-hours of thermal power generation due to water shortages in 2016, canceling out more than 20 percent of growth in the country's total electricity generation from 2015. Between 2013 and 2016, as shown in Figure ES-3, 61 percent of the time programmed daily thermal generation targets couldn't be met due to forced power plant outages, which included equipment failure, fuel shortages, water shortages, and other factors. Based on the Daily Outage Reports disclosed by the Central Electricity Authority (CEA) between 2013 and 2016, water shortage is the fifth–most common reason for forced outages of Indian thermal power plants and caused almost 2 percent of all outages in terms of potential generation.

Among all of India's freshwater-cooled thermal utilities, 39 percent of the capacity is installed in high water-stress regions. That capacity generated 34 percent of the total freshwater-cooled thermal power generation in 2016. Water stress is the ratio of total water

Figure ES-3 | **India's Daily Programmed and Actual Generation from Thermal Power Utilities between 2013 and 2016**

61% of the time, programmed thermal generation couldn't be delivered due to forced power plant outages, including equipment failure, fuel shortages, water shortages, and so on



Source: Data from CEA, compiled and analyzed by WRI authors.

withdrawal over available supply (Gassert et al. 2014). High water stress indicates a high level of competition in water use. Figure ES-4 is a water-stress map with all freshwater-cooled thermal power utilities in India.

Freshwater-cooled thermal power plants that are located in high water-stress areas have a 21 percent lower average capacity factor, compared to the ones in low and medium water-stress areas. Among India's 19 ultra large freshwater-cooled plants (with an installed capacity over two gigawatts), 16 are located in low-and medium water-stress regions. Furthermore, we controlled the comparison analysis by unit age, fuel type, and plant capacity and observed the same trend in almost every control group: Plants in high-stress areas have a lower average capacity factor than those in low and medium water-stress areas.

Some of the most disruptive water shortages occurred in India's most water-abundant area. We also found that, even in water-abundant or low water-stress regions, thermal plants can still face water shortage–related risks during droughts or when monsoons are delayed. Some of those plants—for example, Farakka, Raichur, and Tiroda—experienced significant, if not the biggest, disruptions in generation caused by water shortages.

Fourteen of India's largest thermal power utility companies have experienced water shortage-related disruptions at least once between 2013 and 2016, losing over $1.4 billion in total potential revenue from the sale of power, and are likely to continue facing the problem as water competition intensifies in the future. In 2016, nine companies had water-related shutdown records for 12 of their plants, and together lost more than $614 million in potential revenue, accounting for about 2.3 percent of their total revenue from the sale of power in 2016. For assessing companies' exposure to water risks, we benchmarked India's 20 largest thermal utility companies against four water-related metrics, as shown in Table ES-1.

Freshwater consumption from India's thermal power generation would stay below its 2016 level by 2027 if the country's most aggressive renewable targets are achieved and the notified stringent power-sector water regulations implemented. We analyzed two scenarios—scenario 1 (developed by CEA) and scenario 2 (developed by WRI authors based on CEA's draft national electricity plan)—for the year 2027, as well as the notified power sector water regulations by the Ministry of Environment, Forest, and Climate Change (MOEFCC). We found that, for the thermal power sector under scenario 2, despite a more than 60 percent projected increase in electricity generation, freshwater consumption would stay below the 2016 level, and water withdrawals would be reduced significantly by more than 12 billion cubic meters. However, even maintaining 2016 water consumption levels implies continued risk of electricity outages, competition with other rapidly growing sectors, and increased variability in local water supplies due to climate change.

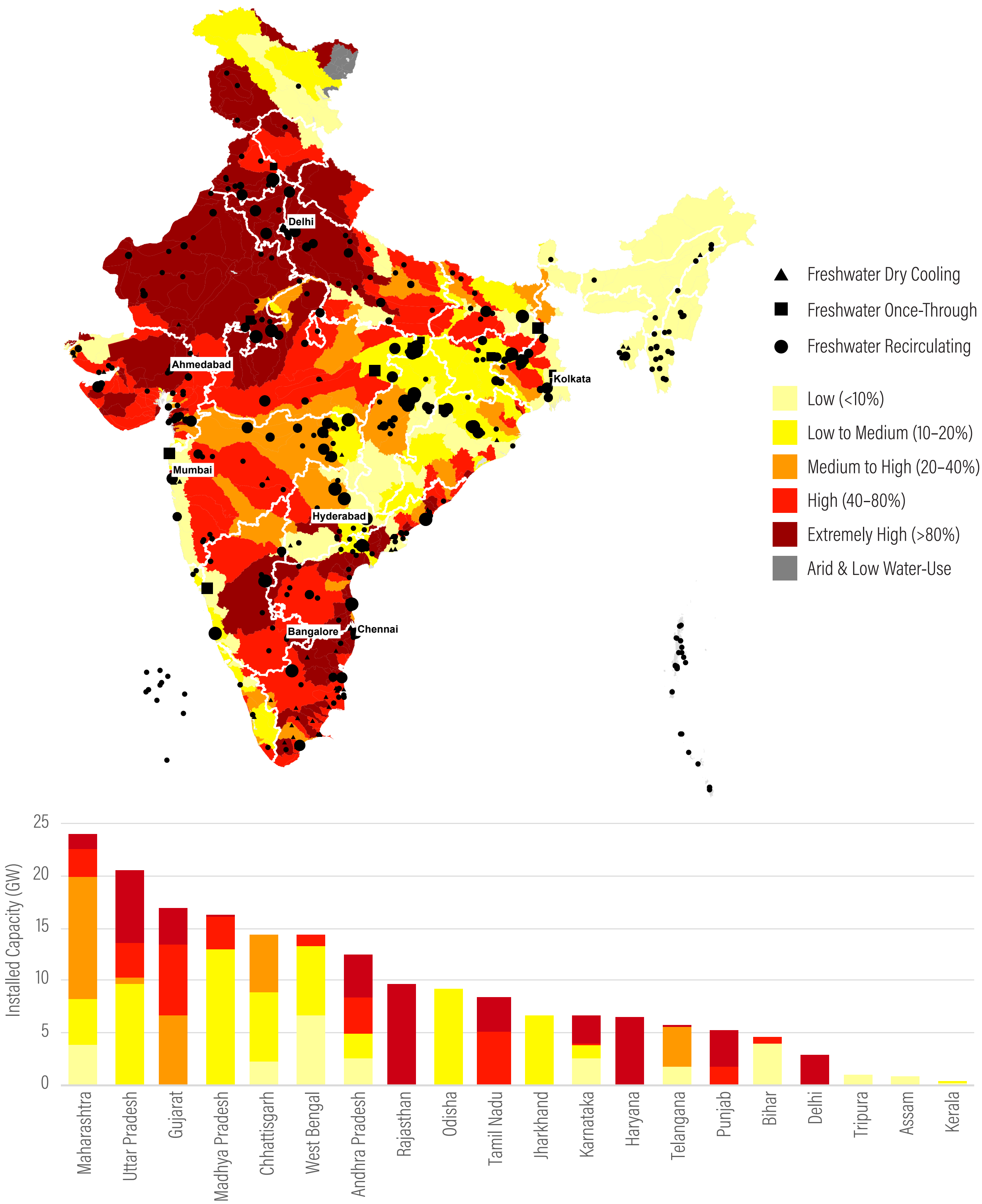
There is a huge data gap in water withdrawal and consumption information for India's power sector. Our research attempts to fill the gap, but the limitations of our method and data cannot substitute for actual ground-level measurement and monitoring. In fact, our estimates of India's total thermal power sector water use could be on the lower end. Additionally, our benchmarking of utility companies does not capture corporate water management practices and technological innovations.

Terms such as "water withdrawal" and "water consumption" are used interchangeably by India's power sector. For example, MOEFCC's notified regulations use the term "specific water consumption," when referring to what is conventionally called "water withdrawal." In fact, power plants in India currently only measure water withdrawal, not consumption. The lack of standardization in terminology could create confusion in water-use monitoring and accounting.

Recommendations

The Ministry of Power, Government of India, should mandate that power plants start monitoring and disclosing water withdrawal and discharge data, leveraging its existing daily reporting system. Currently, there is a significant data gap in power plant water withdrawal and consumption information in India. Unlike the detailed generation and capacity data one can easily find about power plants, water-related data are scarce and difficult to find. Mandating monitoring and disclosure will help promote transparency and accountability in how the power sector manages water resources and build the foundation for assessing risks and measuring progress.

Figure ES-4 | **India's Freshwater-Cooled Thermal Utilities Mapped against Baseline Water Stress and Distribution in Installed Capacity by Water Stress Level by State**



Note: Symbol size reflects the power plant's relative installed capacity.

Source: WRI authors.

Disclaimer: This map is for illustrative purposes and does not imply the expression of any opinion on the part of WRI concerning the legal status of any country or territory or concerning the delimitation of frontiers or boundaries.

Table ES-1 | **Water Dependency and Risk Exposure Benchmarking for India's Largest Thermal Utility Companies as of December 2016**

COMPANY	TOTAL THERMAL CAPACITY (GW)	FRESHWATER WITHDRAWAL INTENSITY (M^3/MWH)	NO. OF ASSETS THAT HAD AT LEAST ONE WATER SHORTAGE-INDUCED SHUTDOWN RECORDED BETWEEN 2013 AND 2016	% REVENUE GENERATED IN HIGH WATER-STRESS AREA	PROJECTED CHANGE IN FUTURE WATER-USE COMPETITION WITH OTHER WATERSHED STAKEHOLDERS
NTPC	40.8	28.1	3	27.2%	9.9%
Adani Power	11.0	2.0	2	6.3%	3.0%
MSEB Holding Co.	10.5	3.5	3	23.0%	27.7%
Damodar Valley Corp.	7.3	3.8	0	0.0%	21.0%
Reliance	6.8	21.1	1	18.1%	13.8%
Tata Group	6.4	0.9	0	22.3%	14.2%
Gujarat State Elec. Corp.	6.0	3.7	1	63.4%	23.1%
Nuclear Power Corp.	5.7	53.3	0	42.4%	10.4%
Uttar Pradesh RV	5.5	35.9	1	57.7%	8.1%
Tamil Nadu Gen. & Dist. Corp.	5.3	4.5	2	40.1%	5.7%
Rajasthan RVUN	5.2	74.4	2	100.0%	5.8%
West Bengal Power Dev. Corp.	4.9	16.7	0	30.6%	8.2%
Andhra Pradesh Power Gen. Corp.	4.5	3.8	1	50.2%	5.9%
MP Power	4.3	83.8	2	46.0%	11.5%
Essar Energy	4.3	3.5	1	99.4%	13.7%
GMR Group	3.7	3.6	1	0.0%	15.3%
Karnataka Power Corp.	3.6	3.8	2	47.7%	15.8%
Haryana Power Gen Co.	3.3	3.8	0	100.0%	-5.2%
Vedanta Resources	3.2	3.6	2	29.1%	9.0%
Torrent Power	3.2	2.2	0	24.3%	18.5%

Top 25%   Upper middle 25%   Lower middle 25%   Bottom 25%

Notes: Only thermal plants are included in the benchmarking exercise. Capacity data are from the Platts World Electric Power Plant database and might have small discrepancies compared to data disclosed by CEA or other sources. Color codes represent relative performance between companies within each metric.

Source: WRI authors.

Reporting on water data monitoring and disclosure for power plants should be standardized. Unlike greenhouse gas emissions, there is no widely recognized guideline or standard on how power plants should account for and report on their water usage. For example, terms such as "water withdrawal" and "water consumption" are used interchangeably by India's power sector. The lack of standardization of terminology and calculation methodologies makes it difficult for utilities to monitor and disclose their water data, discouraging them from reporting, and weakening the comparability and usefulness of the data. A standardized thermal power sector water data reporting method would provide consistency and clarity, help policymakers develop and implement specific water conservation regulations, and guide utility companies in monitoring and disclosing their water performance.

The Ministry of Power, Government of India, should set power sector water performance benchmarking guidelines and create policy guidelines and incentives for better performers. Water dependency and risk exposure vary greatly among companies. Some are more freshwater efficient and have less environmental impact than others. Both public and private power utility companies' water performance should be benchmarked with standardized monitored data and corporate disclosure. Utilities that are better at managing water and controlling risks have lower chances of disruptions in their services during extreme drought and should be recognized and rewarded for their effort and ability to provide greater stability and more reliable services through regulations and incentives created by the Ministry of Power.

Thermal power utility companies should investigate and assess their water-related risks to identify assets at risk and invest in risk-mitigation or reduction efforts to ensure business continuity and to prepare for future uncertainty. Some Indian power plants have experienced significant, if not the biggest, disruptions in electricity generation, caused purely by water shortages in recent years. Conducting a portfolio-level assessment on water dependency and risk exposure is the key to understanding risks, prioritizing resources, and informing effective mitigation strategies. Additionally, climate change impacts and economic growth will add additional challenges, making it crucial to reassess watershed hydrology at the individual power plant level, including quantifying potential changes in drought probabilities to inform contingency plans and long-term business development planning.

Public and private sector investors should assess their investment portfolios' exposure to water risks, identify highly exposed companies, and urgently engage those companies in promoting better water management practices and reducing such risks. Fourteen of India's 20 largest thermal utility companies experienced water shortage–induced power plant shutdowns at least once between 2013 and 2016, losing more than $1.4 billion in total in potential revenue from the sale of power. Additionally, these companies are likely to see an increase in water-use competition by 2030 and therefore would continue experiencing water-related disruptions if they continue business as usual. Investors (including public financial institutions like development banks) should leverage water risk assessment to engage with companies in which they invest, further identifying company strategies to address water scarcity issues, and ultimately pushing companies to be more sustainable and socially responsible, thereby benefiting both people and the environment.

The Government of India should keep working toward meeting its ambitious renewable goals and should prioritize solar PV and wind projects when possible, to scale up power production while reducing the power sector's exposure to water-related risks. Under the scenario 2, by 2027, India's power sector (hydro excluded) would see a 76 percent decrease in water withdrawal intensity; more than 32 percent of that reduction is driven by the country's power mix shifting toward more solar PV and wind. Water consumption intensity would decrease by about 25 percent; almost 98 percent of that reduction would be driven by the power mix shift. Compared to cooling technology advancement or plant efficiency enhancement, transitioning to more solar PV and wind generation is the only pathway at scale that can cut back both water withdrawal and consumption while sustaining growth in power generation. This is essential to reducing not only the power sector's water dependency and exposure to water risks, but also its impact on the ecosystem and other water users at the national scale.

INTRODUCTION

Since 2000, India has been making great progress in expanding its power supply to meet the country's steadily growing demand (IEA 2016; BP 2017). Access to electricity improved from 60 percent of the population in 2000 to 79 percent of the population in 2014 (World Bank 2017). More than three quarters of India's electricity is generated from thermal power plants (CEA 2017), which rely significantly on freshwater needs for cooling purposes.

India is one of most water-stressed countries in the world, and freshwater resources are scarce in most parts of the country (Shiao et al. 2015). India's thermal power sector has suffered from water shortages and lost tens of terawatt-hours of generation and billions of dollars of revenue in the past few years (Luo 2017), posing threats to both Indian society and companies.

Additionally, as India's economy and demand for power continues to expand, the country's water demand also is expected to grow significantly across sectors by 2050 (CWC 2015). The competition for available water is only going to become more intense (MWR 2012).

To address these issues, the Government of India has developed several promising plans, including capping "specific water consumption" for thermal power plants (MOEFCC 2015b), requiring certain plants to use treated wastewater for cooling (MOP 2016), setting ambitious targets for renewable energies that are almost water-independent (MOEFCC 2015a), and proposing new water allocation and management principles (MOWR 2012).

It is our goal to help decision-makers understand the magnitude of water issues in the power sector in India and to provide information that the country can use for informed decision-making in the future. To do this, WRI authors used data science techniques and innovative methodologies and developed a comprehensive plant-level geodatabase on water withdrawal and consumption for India's power sector. Combined with water risk data from WRI Aqueduct™ and power projections from India's Central Electricity Authority (CEA), we quantified the Indian power sector's water demand, assessed its exposure to water risks, and evaluated opportunities for reducing water demand while supporting power growth for the future.

DATA AND METHODOLOGY

Estimates for water withdrawal and consumption attributable to the Indian energy sector vary considerably (Chaturvedi et al. 2017; IEA 2016; Bhattacharya and Mitra 2013). The primary reason is the huge data gap in power plant cooling type and water usages, specifically, the lack of information on power sector cooling technology shares and Indian specific power plant water withdrawal and consumption factors.

In this study, WRI used data science techniques and innovative methodologies to fill the data gap, and produced the most up-to-date water-related data at plant level for India's power sector. **Here are the three most valuable and unique aspects about the data we developed and used in this study:**

- By applying a recently developed WRI methodology that draws from high resolution satellite images to identify power plant cooling technology, we created a plant-level geodatabase on cooling technology and water sources that represents the on-the-ground situation in 2016 (Luo et al. 2018).
- We collected four years of daily generation reports and eight years of monthly reports from India's Central Electricity Authority (CEA) for each plant for which CEA discloses data and structured this information into machine-readable data sets.
- We developed a data imputation model to fill in missing values of cooling and source water types and capacity factors, leveraging a random forest-based machine learning algorithm trained with observations from the previous two steps. Please refer to the appendix for details on the imputation method and performance.

The newly developed data made it possible to:

- provide a more accurate estimate of annual freshwater withdrawal and consumption by India's power sector as a whole from 2011 through 2016;
- develop a water withdrawal and consumption time series for individual power plants;
- analyze power sector water-use behavior both spatially and temporally at any scale, including plant, city, watershed, state, and national; and
- evaluate future power sector (hydro excluded) water demand in combination with power mix projections.

Scope

In this study, unless stated otherwise, we focus on thermal power utilities, both government/privately owned utilities and private power producers, and include all plants fueled by coal, nuclear, oil, gas, biomass, and concentrated solar power. Unless otherwise noted, we excluded from all our analyses captive plants, power plants that are owned and operated by industrial and commercial energy users for their own energy consumption.

We differentiate between water withdrawal and consumption in power plant water use. Withdrawal is the amount of water diverted from a water source. Some portion of the withdrawal is evaporated or consumed during the generation process, which is defined and measured as consumption.

The quantification of water withdrawal and consumption is bounded within power plants themselves and for power generation only. Water demand associated with upstream and downstream energy sector activities like fuel production and electricity consumption is not included in our analysis.

Cooling technologies are grouped into three generic categories: once-through, recirculating, and dry cooling. Please refer to Luo et al. (2018) for details on cooling technology definition and system diagrams.

In this study, we focus on water shortage–related risks only. Other types of risks associated with water—for example, water temperature, water quality, and flooding—are beyond the scope of this paper.

Data Sources

To fill the data gap to the highest possible degree, we harnessed the best available data for each portion of our model and compiled them into a master geodatabase for our analysis. Table 1 is a list of source data we drew upon to build the plant-level water withdrawal and consumption database and conduct the assessment on water use, risks, and opportunities for India's power sector.

Methodology

For developing the plant-level water withdrawal and consumption database, we applied the following six-step approach:

- Plant inventory development. The Platts database was used as the inventory from which we developed a full list of 478 thermal power plants that were in operation in India as of December 2016. The inventory database includes information on plant name, installed capacity, fuel type, company name, parent company name, installation year, city and state, and business type at the generating unit level.
- Power plant geocoding. Through a public power plant geolocation database—for example, Global Energy Observatory and others—and Internet research, we geolocated and validated on Google Maps the exact latitude and longitude of 358 plants covering about 204 GW, which accounts for almost 99 percent of the total capacity of all thermal power utilities, according to Platts data.
- Cooling technology identification. We analyzed satellite images for all geolocated utilities and identified water source and cooling type by applying the methodology from Luo et al. (2018).
- Assignment of water withdrawal and consumption factors. We used Indian specific water withdrawal and consumption factors from Chaturvedi et al. (2017), when available, and assigned factors to each plant by its cooling and fuel type following the method described in Luo et al. (2018). Detailed water factors may be found in the appendix.
- Annual capacity factor calculation. Eight years of plant-level annual capacity factors are calculated by averaging plant-level monthly capacity factors within each year, estimated with monthly generation and capacity data from CEA. The estimated plant-level annual capacity factors are then matched back to the plant inventory database (step a). In this way, we matched 93.8 percent of the total capacity in the inventory.
- Missing data imputation. A random forest-based machine learning algorithm was used in imputing missing values of cooling and source water type for the plants we were not able to geolocate and capacity factors for the plants for which we could not find generation data from CEA. Details about our imputation model may be found in the appendix.

Table 1 | **A List of Source Data Used in the Study**

DATA	TIME FRAME	AVAILABILITY	SOURCES
Plant and regional-level daily generation data	January 2013–December 2016	Public	CEA data compiled by WRI authors
Plant-level monthly generation and capacity data	January 2008–December 2016	Public	CEA data compiled by WRI authors
Unit-level rate of sale of power data	Fiscal year 2015	Public	CEA data compiled by WRI authors
Unit-level daily outage data	January 2013–December 2016	Public	CEA data compiled by WRI authors
Country-specific water withdrawal and consumption factors by fuel and cooling type	Not applicable	Public	Chaturvedi et al. (2017); CWR/IRENA (2016); Bhattacharya and Mitra (2013); NREL (2011)
Unit-level capacity, built year, operating status, fuel, business type, and ownership data	Calendar year 2016	Proprietary	The Platts World Electric Power Plants Database
Catchment-level current water supply, demand, and stress data	Calendar year 2010	Public	Gassert et al. (2014)
Catchment-level projected future water supply, demand, and stress data	Calendar year 2030	Public	Luck et al. (2015)
National-level entire power sector generation and capacity data	Calendar year 2014	Public	Courtesy of IRENA (International Renewable Energy Agency)
National-level projected future power mix, generation, and capacity	Calendar year 2027	Public	Courtesy of CEA

Limitations

In this paper, neither water quality–or water temperature–related risk is studied because those risks were never attributed as the reason for any of the shutdowns, according to CEA's daily outage reports.

Most of the water withdrawal and consumption factors we used are Indian median values from Chaturvedi et al. (2017) because an individual power plant does not disclose its actual water-use data publicly, and no consistent database was available that reports plant-specific factors with good coverage.

Hydroelectric power plants are not studied in this paper because of the difficulty of quantifying water consumption with a reasonable level of accuracy using the data available to us.

Captive plants are excluded from this study because of the data limitations at the plant level.

WATER USE, RISKS, AND OPPORTUNITIES FOR INDIA'S THERMAL POWER SECTOR

Water Demands

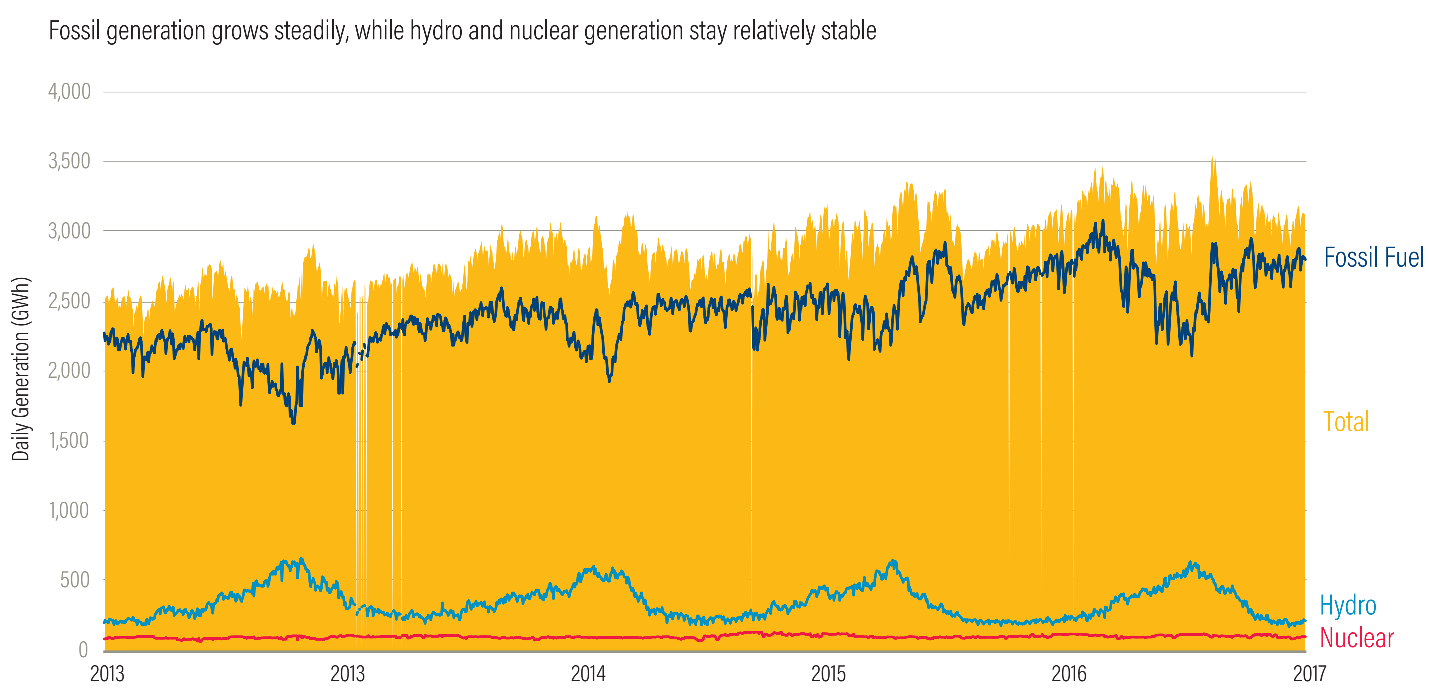
Almost 90 percent of India's thermal power generation is dependent on freshwater for cooling.

As its economy grows, India's demand for electricity has been increasing rapidly over the past decades (CEA 2017). Figure 1 shows how much electricity India's fossil, nuclear, and hydropower sectors have been generating every day between 2013 and 2016. Nuclear and hydro generation has been fairly stable on an annual basis, despite the strong seasonality of available water to produce electricity that one can observe in the hydropower sector. In contrast, fossil fuel generation has been on the rise, as shown in Figure 1.

Taking a closer look at the thermal (fossil and nuclear) power sector, as illustrated in Figure 2, we found that forced outages are consistently happening throughout the year, and plants are often (61 percent of the time) generating less than what they had planned or been programmed to do in their annual generation targets. According to CEA's daily outage reports, there are many reasons for forced outages, including fuel shortages, mechanical problems, lack of available cooling water, and others. More discussion of this can be found in Section 3.2.

In 2016, thermal (fossil and nuclear) electricity accounted for more than 83 percent of India's total utility power generation (CEA 2017), and almost 90 percent of that depended on freshwater for cooling, as shown in Figure 3, according to our analysis. The very high dependency on freshwater resources makes the country's thermal power

Figure 1 | **India's Daily Fossil, Hydro, Nuclear, and Total Generation between 2013 and 2016, Solar and Wind Excluded**

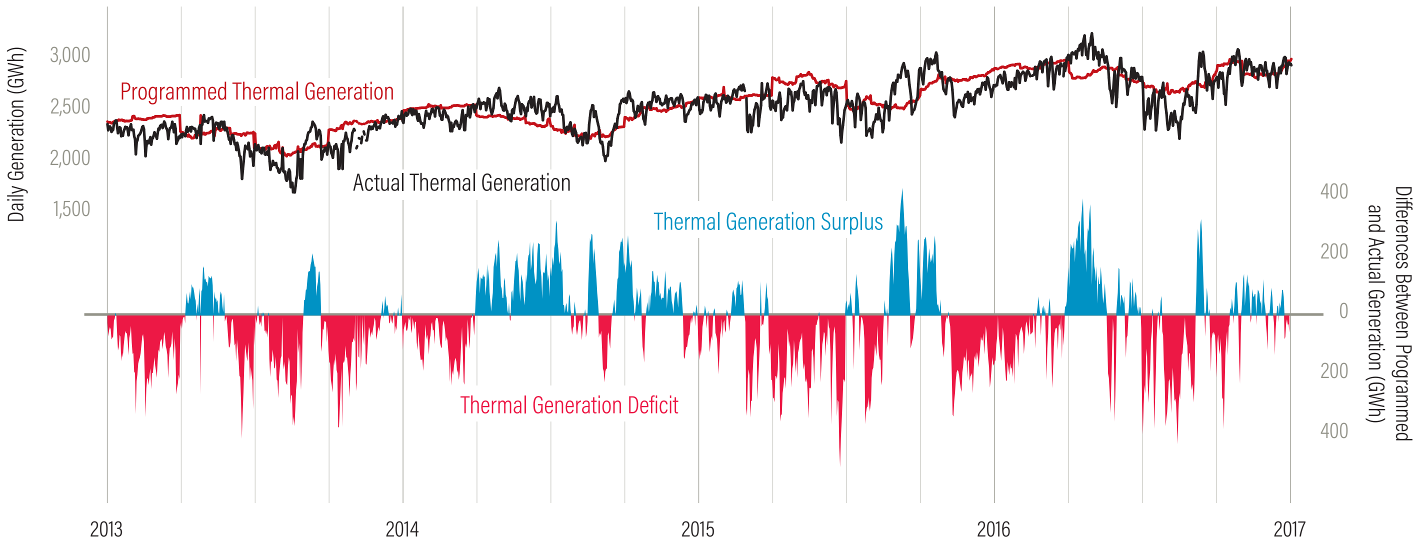


Note: Electricity generated by solar and wind accounted for about 3.3% of India's total power generation in 2014 according to IRENA, but is not shown on this graph, due to data availability from CEA. Vertical white strips indicate no data on that day from CEA.

Source: Data from CEA, compiled and analyzed by WRI authors.

Figure 2 | **India's Daily Programmed and Actual Generation from Thermal Power Utilities between 2013 and 2016**

61% of the time, programmed thermal generation couldn't be delivered due to forced power plant outages, including equipment failure, fuel shortages, water shortages, and so on



Source: Data from CEA, compiled and analyzed by WRI authors.

sector extremely vulnerable to water risks like drought and freshwater scarcity from competition with other sectors. Figure 4 is a map showing the spatial distribution of all Indian thermal power plants by its source water type and cooling technology.

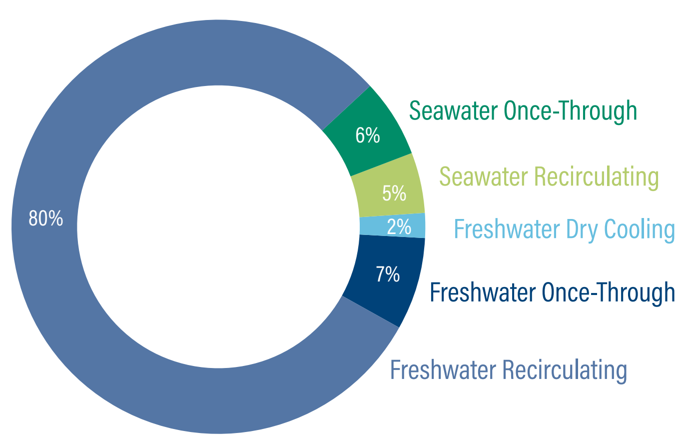
Table 2 lists our estimates of India's thermal power utility cooling technology distribution by source water, fuel, and cooling type in 2016. Distributions are shown in percentages in both generation and capacity. For freshwater-cooled utilities, our analysis with satellite images found that 13 utilities use once-through cooling systems, which is by far the most water withdrawal–intensive technology. These 13 plants account for roughly 6 percent of India's total thermal capacity in 2016 and are mostly located in low water-stress areas in the northeastern part of the country.

About 3 percent of India's thermal electric power capacity uses dry cooling technology, which is the least water withdrawal–intensive approach compared to once-through cooling. These are mostly concentrated in the west and the south, where water is a scarce resource. The rest, almost 82 percent of the country's total thermal capacity, is cooled with freshwater-recirculating cooling towers that typically withdraw a lot less but consume more water than once-through systems do.

Twelve power plants use seawater instead of freshwater for cooling. They make up about 8.8 percent of India's total thermal capacity and are mostly located in the states of Tamil Nadu, Gujarat, and Maharashtra.

Figure 3 | **2016 India's Thermal Utility Power Generation Distribution by Water Source and Cooling Technology**

In 2016, almost 90% of India's thermal utility power generation used freshwater for cooling



Source: Data from CEA, compiled and analyzed by WRI authors.

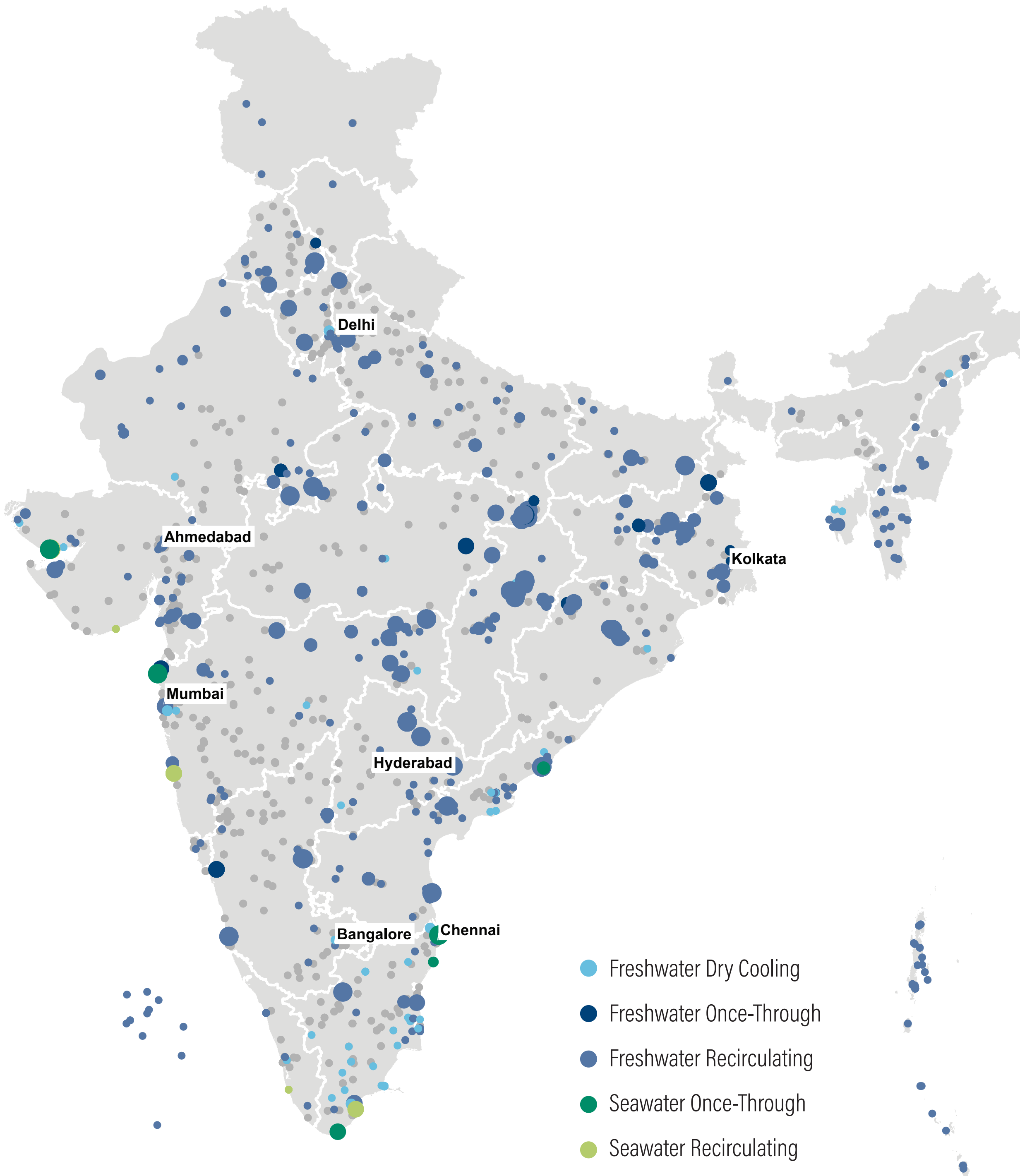
Table 2 | **India's Thermal Power Utility Cooling Technology Distribution in 2016**

SOURCE WATER, FUEL, AND COOLING TYPE	% TOTAL THERMAL GENERATION IN 2016	% TOTAL THERMAL CAPACITY IN 2016
Freshwater—coal—recirculating	73.4%	69.8%
Freshwater—coal—once-through	6.4%	5.8%
Seawater—coal—once-through	4.6%	3.7%
Seawater—coal—recirculating	4.6%	3.3%
Freshwater—gas—recirculating	3.1%	6.2%
Seawater—nuclear—once-through	1.5%	1.3%
Freshwater—nuclear—recirculating	1.5%	1.0%
Freshwater—other—recirculating	1.3%	2.7%
Freshwater—gas—dry cooling	0.9%	1.5%
Freshwater—nuclear—once-through	0.8%	0.4%
Freshwater—coal—dry cooling	0.6%	1.0%
Freshwater—oil—recirculating	0.4%	1.3%
Freshwater—other—dry cooling	0.3%	0.6%
Freshwater—biomass—recirculating	0.3%	0.4%
Freshwater—biomass—dry cooling	0.1%	0.1%
Freshwater—solar—recirculating	0.1%	0.1%
Seawater—other—recirculating	0.0%	0.2%
Seawater—oil—recirculating	0.0%	0.1%
Freshwater—oil—dry cooling	0.0%	0.2%
Seawater—gas—recirculating	0.0%	0.2%

Note: This table includes all thermal utilities included in our inventory database: 93.8%, capacity-wise, of the source water and cooling type data is developed by analyzing satellite images, the remaining 6.4% of the data is generated with our imputation model.

Source: WRI authors.

Figure 4 | **A Map of India's Thermal Power Plants by Cooling Water Source and Cooling Technology Type**



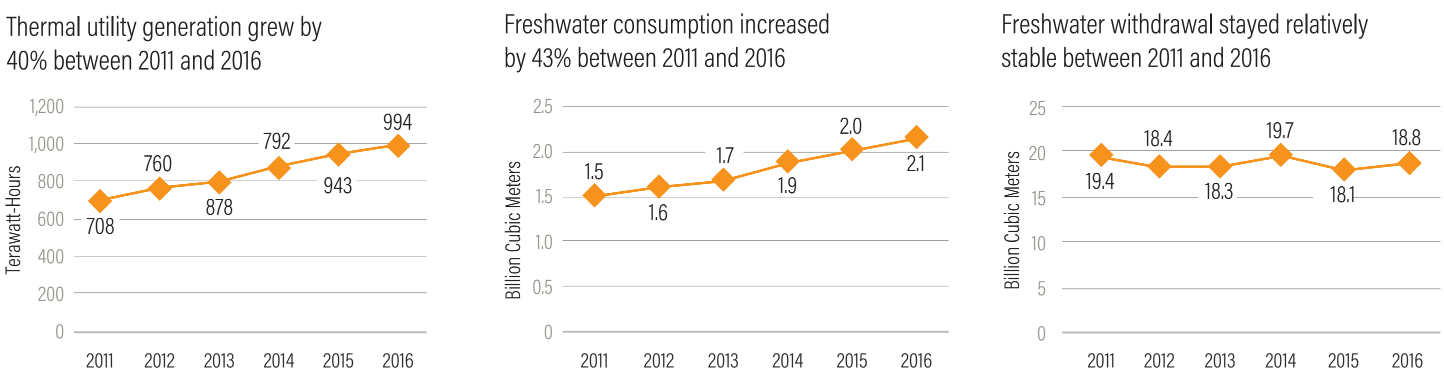
Sources: WRI authors.
Disclaimer: This map is for illustrative purposes and does not imply the expression of any opinion on the part of WRI concerning the legal status of any country or territory or concerning the delimitation of frontiers or boundaries.

While generation from India's thermal utilities grew by 40 percent between 2011 and 2016, their freshwater consumption increased by 43 percent, from 1.5 billion cubic meters in 2011 to 2.1 billion in 2016.

According to our analysis, freshwater consumption by thermal power plants in India has been rising over the past six years, from 1.5 billion cubic meters in 2011 to 2.1 billion in 2016, an increase of 43 percent, as shown in Figure 5. We believe there are two primary factors driving the increase: (1) the steady growth in electricity generation, an increase of 40 percent between 2011 and 2016, and (2) the increased share of recirculating cooling systems, which are more water consumptive than other technologies, as illustrated in Figure 6.

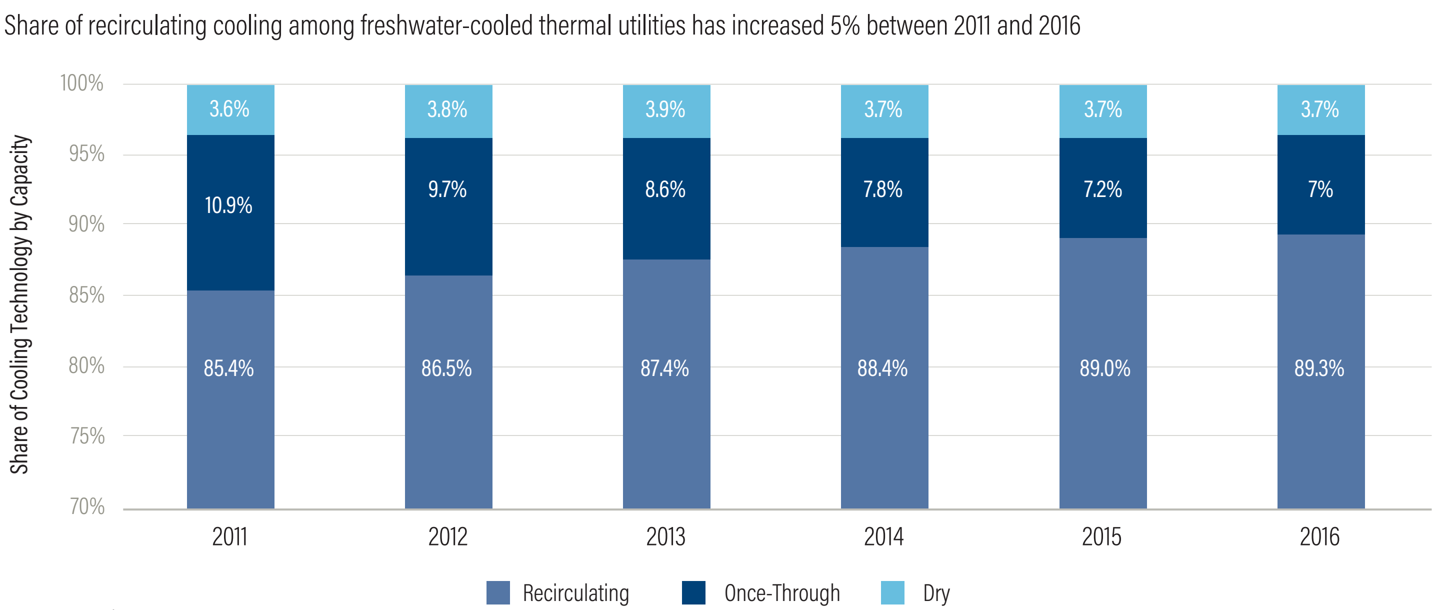
It is important to distinguish here between consumption—water that is kept within the plant's cooling towers or evaporated to the atmosphere—and withdrawal, of which a large portion (as much as 99 percent, depending on cooling technology and fuel type) may be returned to rivers and lakes and become available for use again downstream.

Figure 5 | **India's Annual Thermal Utility Generation, Freshwater Consumption, and Withdrawal between 2011 and 2016**



Sources: WRI authors; CEA (2017).

Figure 6 | **Share of Cooling Technology of Freshwater-Cooled Thermal Utilities by Installed Capacity from 2011 through 2016**



Source: WRI authors.

While consumption has been on the rise, total freshwater withdrawal by India's thermal utilities has remained fairly stable with very small fluctuation (less than 5 percent) in the past six years, and was roughly 18.8 billion cubic meters in 2016. The reason is that once-through plants withdraw water at a rate of 50 times or higher compared to other types of plants, accounting for almost 85 percent of total power sector withdrawals in India, and no new freshwater once-through plant has been introduced after 2011, according to Platts.

The small fluctuations in total water withdrawal from one year to another can be mainly attributed to the variation in actual generation of all once-through power plants. Even though the number of recirculating plants is increasing, the amount of additional water withdrawal from the new recirculating plants is much smaller compared to the changes in withdrawal due to the fluctuation in once-through plant generation.

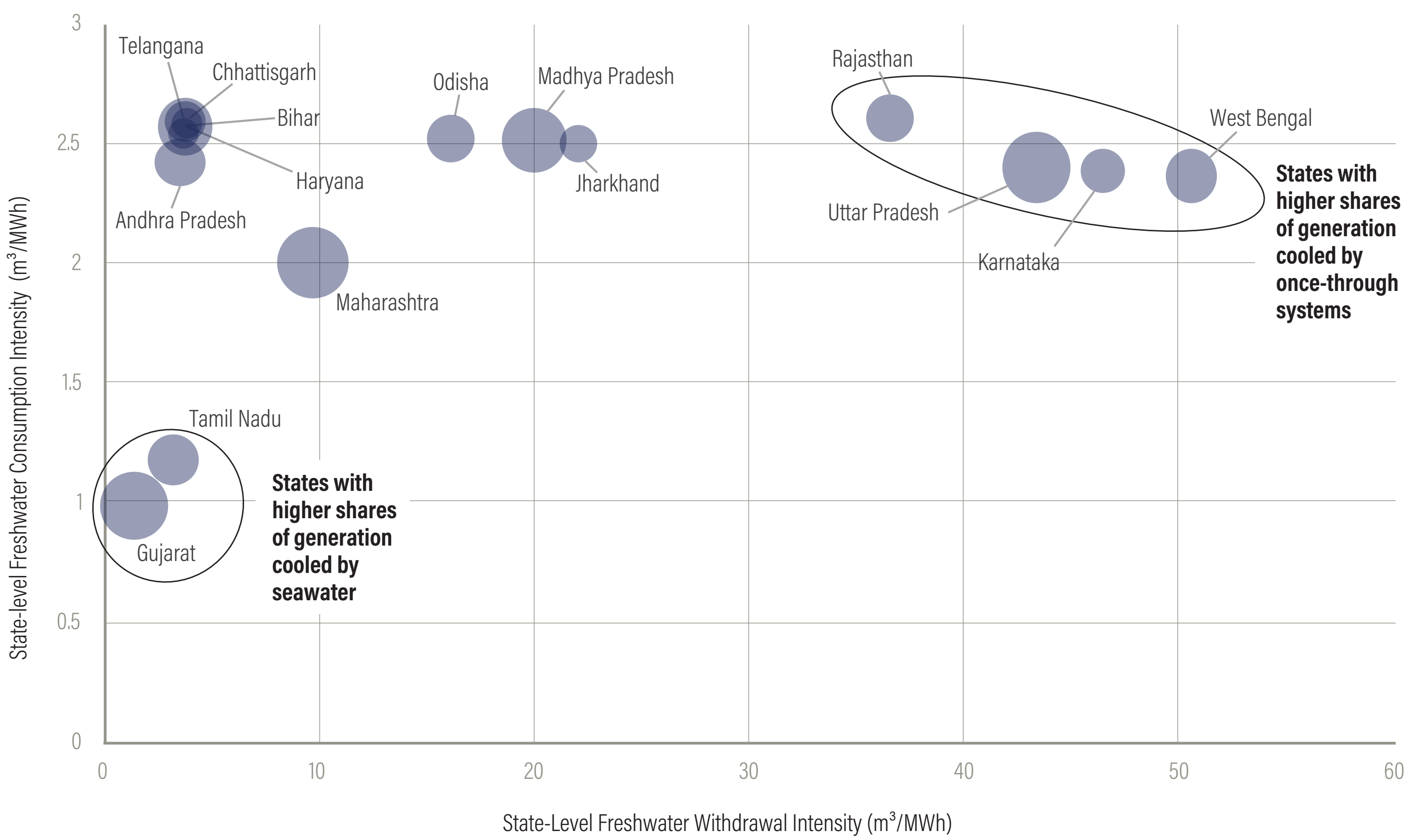
However, our estimates could be on the lower end because our method does not account for water withdrawn and consumed when power plants are not generating electricity. In the United States, more than 30 percent of all thermal power plant water withdrawal occurs when the plants are not generating electricity (Clement et al. 2017), particularly for peak load plants. Cooling systems might be kept running to maintain dispatchability.

Additionally, India's thermal power sector had an estimated freshwater consumption intensity of 2.2 m^3/MWh, and a withdrawal intensity of 18.9 m^3/MWh, at the portfolio level (i.e., across all utilities) in 2016. The key factors determining these numbers include cooling water source, cooling technology share, and power mix.

Cooling water source is relatively straightforward. Plants that use seawater to cool do not consume any freshwater, but others do. Cooling systems can be generally grouped

Figure 7 | **Statewide Average Freshwater Withdrawal Intensity vs. Consumption Intensity of the 15 Largest Thermal Electricity Producing States**

Some states are much more freshwater efficient than others when generating thermal electricity



Note: Bubble size denotes thermal generation for each state relative to others in 2016.

Source: Data from CEA and Platts, analyzed by WRI authors.

into three categories, once-through, recirculating, and dry cooling. Each has different water withdrawal and consumption rates because of their different heat transfer processes. Different kind of fuels have different thermal efficiencies. The more thermal-efficient a fuel is, the less waste heat per unit of generation it produces, thus the less water it needs for cooling.

Different regions or states in India have different priorities when it comes to determining those three factors for power projects. For example, Gujarat is very dry but has long coastlines, so seawater cooling is used more extensively. In contrast, West Bengal is much more water abundant, thus freshwater once-through plants are feasible there. Figure 7 visualizes the statewide average freshwater withdrawal intensity against consumption intensity for the 15 largest power producing states in India.

As illustrated in Figure 7, states like Gujarat and Tamil Nadu both have a high share of electricity generated by seawater-cooled plants, resulting in low intensity levels in both freshwater withdrawal and consumption. On the other end of the spectrum, states like West Bengal, Karnataka, Uttar Pradesh, and Rajasthan have relatively high shares of their thermal electricity generated by once-through plants, making them extremely high in terms of withdrawal intensity at the portfolio level.

Risks

Among all India's freshwater-cooled thermal utilities, 39 percent of its capacity is installed in high water-stress regions, generating 34 percent of its generation.

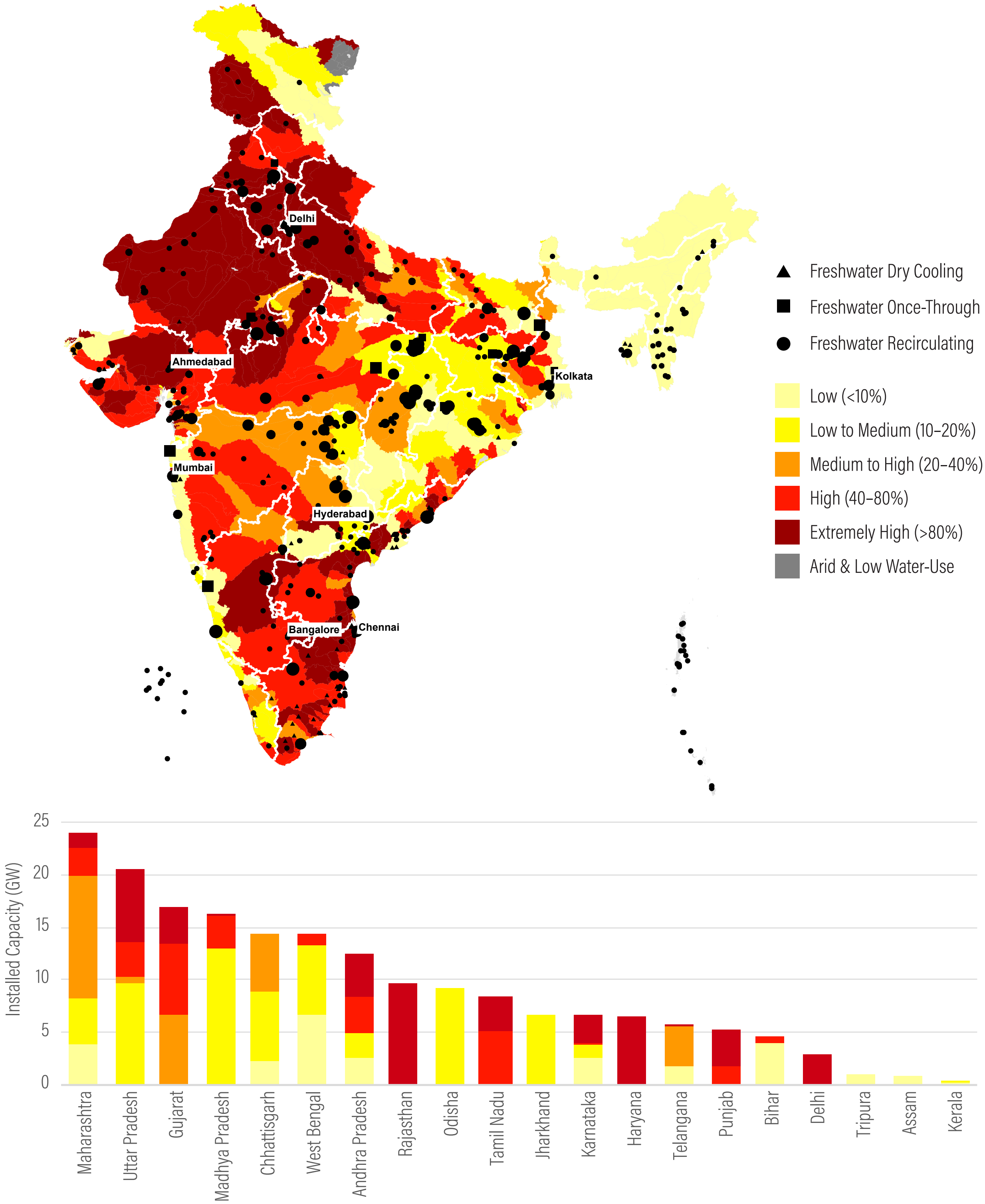
Understanding the thermal power sector's water constraints at the state and national level is important because most economic and regulatory decisions are made at this level. At the same time, it is important to understand water demand and supply at the watershed level, including water demands from other sectors, because these dynamics have a substantial bearing on potential electricity generation capacity.

Water flows across administrative boundaries, and upstream water-use activities, have implications for downstream user access to water despite state or national boundaries. Existing power plants could suffer from decreased water supply from increased upstream irrigated agricultural activities and might affect water supply for nearby downstream cities or villages and limit their population and economic growth.

Therefore, we further examined India's thermal power plants at the watershed level using the WRI Aqueduct™ Global Water Risk Atlas. Figure 8 is a map of all freshwater-cooled thermal utilities against Aqueduct's Baseline Water Stress metric (Gassert et al. 2014), a risk metric that measures the ratio of water demand over supply to reflect the level of competition in a watershed. The figure also includes a bar chart illustrating installed capacity distribution by water-stress level by state. For any catchment, if the water demand and supply ratio is over 40 percent—meaning more than 40 percent of available water is needed and withdrawn for human use—it would be considered in high water stress, which is typically the threshold we recommend to use when identifying water-stress hotspots.

Among all freshwater-cooled plants, in 2016, about 38.9 percent of the total generating capacity across India was installed in high (or extremely high) water-stress regions. However, these plants only generated 33.6 percent of the total freshwater-cooled thermal generation.

Figure 8 | **India's Freshwater-Cooled Thermal Utilities Mapped against Baseline Water Stress and Distribution in Installed Capacity by Water Stress Level by State**



Note: Symbol size reflects the power plant's relative installed capacity.

Source: WRI authors.

Disclaimer: This map is for illustrative purposes and does not imply the expression of any opinion on the part of WRI concerning the legal status of any country or territory or concerning the delimitation of frontiers or boundaries.

India lost 14 terawatt-hours of potential thermal generation due to water shortages in 2016, canceling out more than 20 percent of its growth in total electricity generation from 2015.

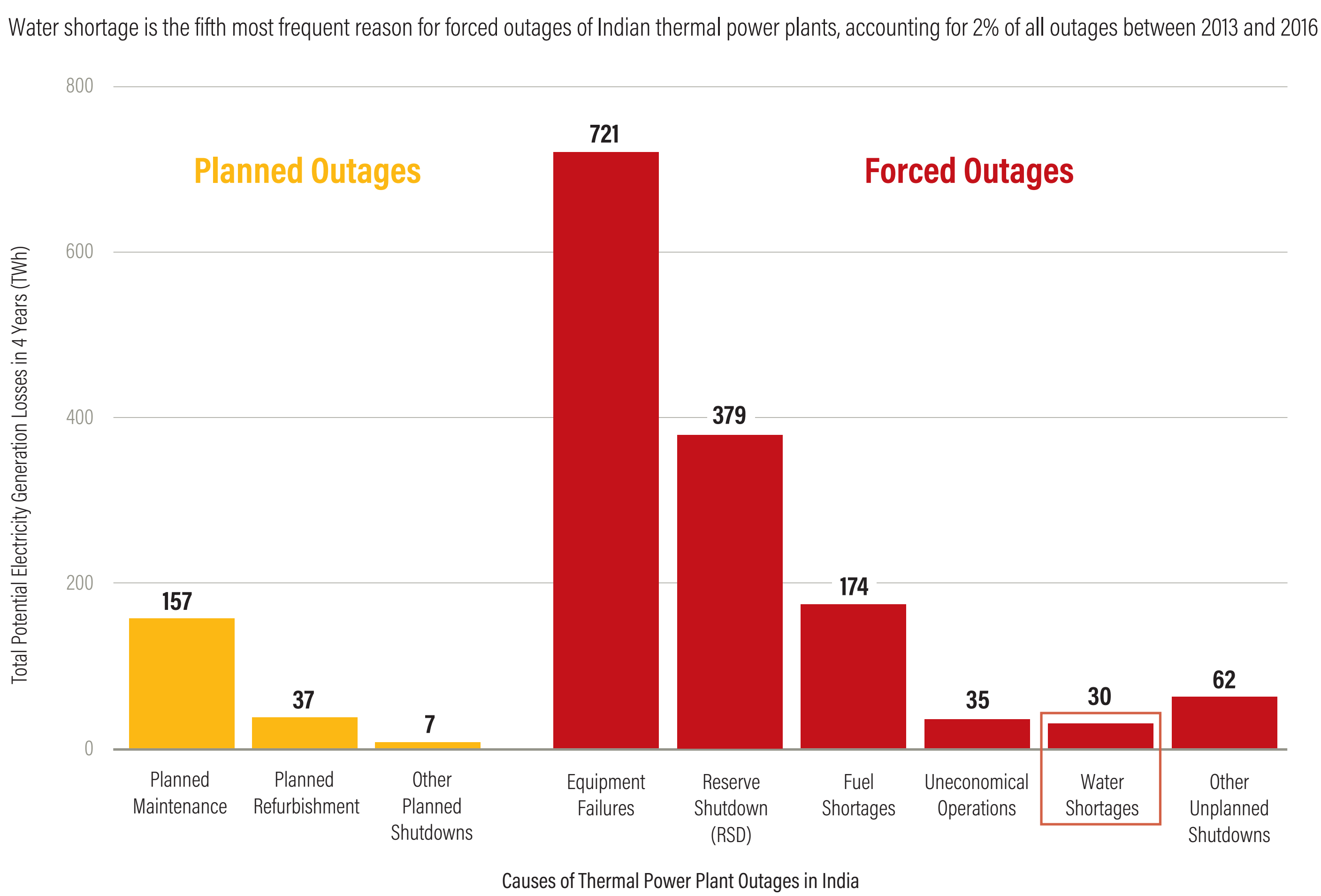
Thermal utilities around India have been suffering from forced shutdowns due to water shortages. We collected and analyzed daily outage reports published by CEA, which disclosed daily which generating unit of which power plant was out as well as the cause of the shutdown.

We found that from 2013 through 2016, India's thermal power sector lost roughly 30 TWh in potential power generation purely due to water shortages, as shown in Figure 9. Potential power generation is calculated by multiplying the installed capacity that is out by the duration (in hours) of the outage.

CEA groups outages into two categories: planned and forced. As illustrated in Figure 9, planned outages include maintenance, refurbishment, and other planned activities, accounting for about 13 percent of all outages (in TWh) between 2013 and 2016. Forced outages include reserve shutdowns, which are defined by CEA and include outages caused by threat to grid security, low demand, transmission congestion, and other anticipated reasons. Other forced outages include outages caused by equipment failure, fuel shortages, uneconomical operations, water shortages, and other unanticipated shutdowns.

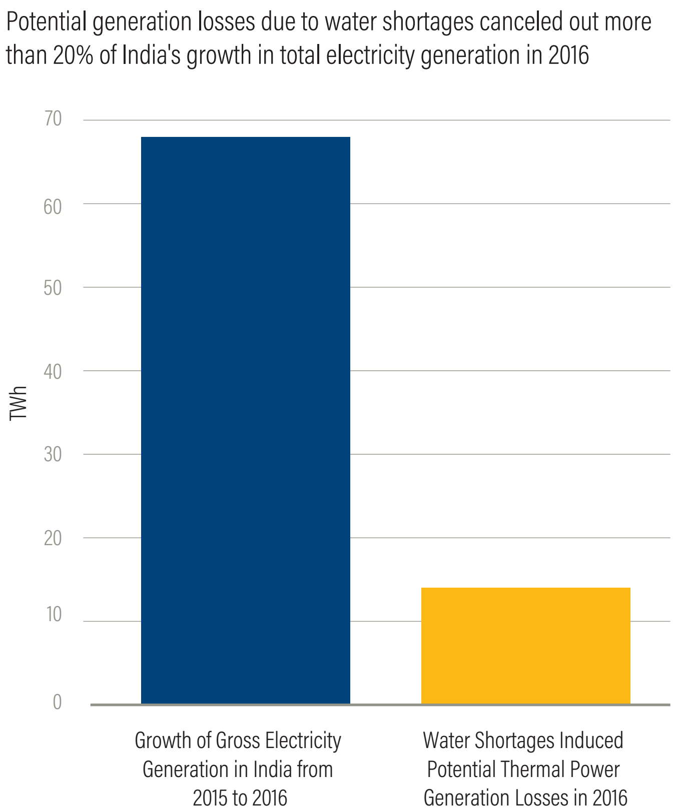
Between 2013 and 2016, water shortage was the fifth most frequent reason for forced outages of Indian thermal power plants and caused almost 2 percent of all outages. In 2016 alone, water shortage–induced potential thermal generation losses canceled out more than 20 percent of India's growth in total electricity generation between 2015 and 2016, as shown in Figure 10.

Figure 9 | **A Breakdown of Planned and Forced Outages of India's Thermal Power Sector by Outage Cause between 2013 and 2016**



Source: Data from CEA, compiled and analyzed by WRI authors.

Figure 10 | **Comparing Water Shortage-Induced Potential Thermal Power Generation Losses with the Growth of Gross Electricity Generation in India in 2016**

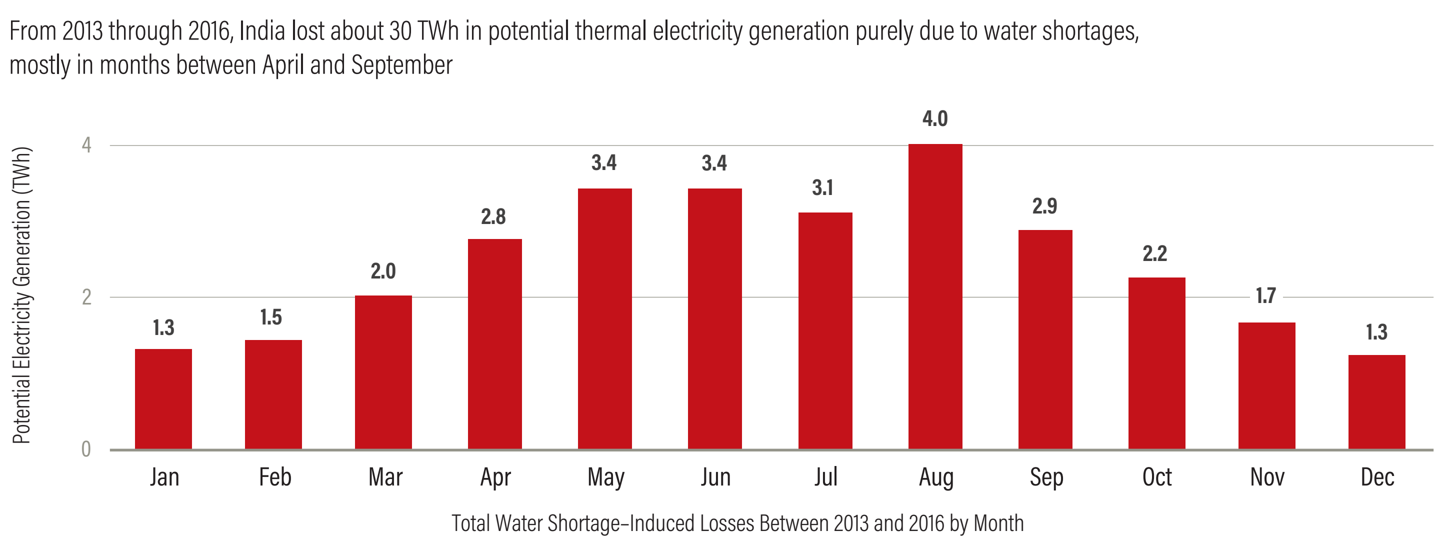


Source: Data from CEA, compiled and analyzed by WRI authors.

Most of the water shortage–induced outages occurred between April and September of the four years (from 2013 through 2016), as illustrated in Figure 11. These outages were largely driven by low water availability in the summer and delayed monsoons. Additionally, the outages were primarily concentrated in water-stressed states like Maharashtra, Gujarat, and Karnataka. A breakdown table of water shortage–induced potential losses in generation, by state, can be found in the appendix.

CEA's daily outage reports provided real evidence and enabled us to conduct a quantitative assessment of the severity of the impact from water shortages on India's thermal power sector. However, we did find some inconsistency and ambiguity in the outage reasons reported in CEA's reports. For example, in some instances we found that a unit was recorded as having to shut down due to cooling water pump problems, according to CEA, but, according to news reports, was offline because of water unavailability. To further understand the possible impact of water shortages on thermal generation, we analyzed capacity factors across India's thermal power generation portfolio.

Figure 11 | **Total Water Shortage-Induced Losses in Potential Electricity Generation between 2013 and 2016, by Month**



Source: Data from CEA, compiled and analyzed by WRI authors.

Freshwater-cooled thermal utilities that are located in high water-stress areas have a 21 percent lower average capacity factor, compared to the ones in low- and medium-stress regions.

Figure 12 shows the national average capacity factors, weighted by installed capacity, by exposure to water stress, cooling water source, and cooling technology. Freshwater-cooled plants that are located in high water-stress regions have a 21 percent lower average capacity factor compared to the ones in low-and medium-stress regions.

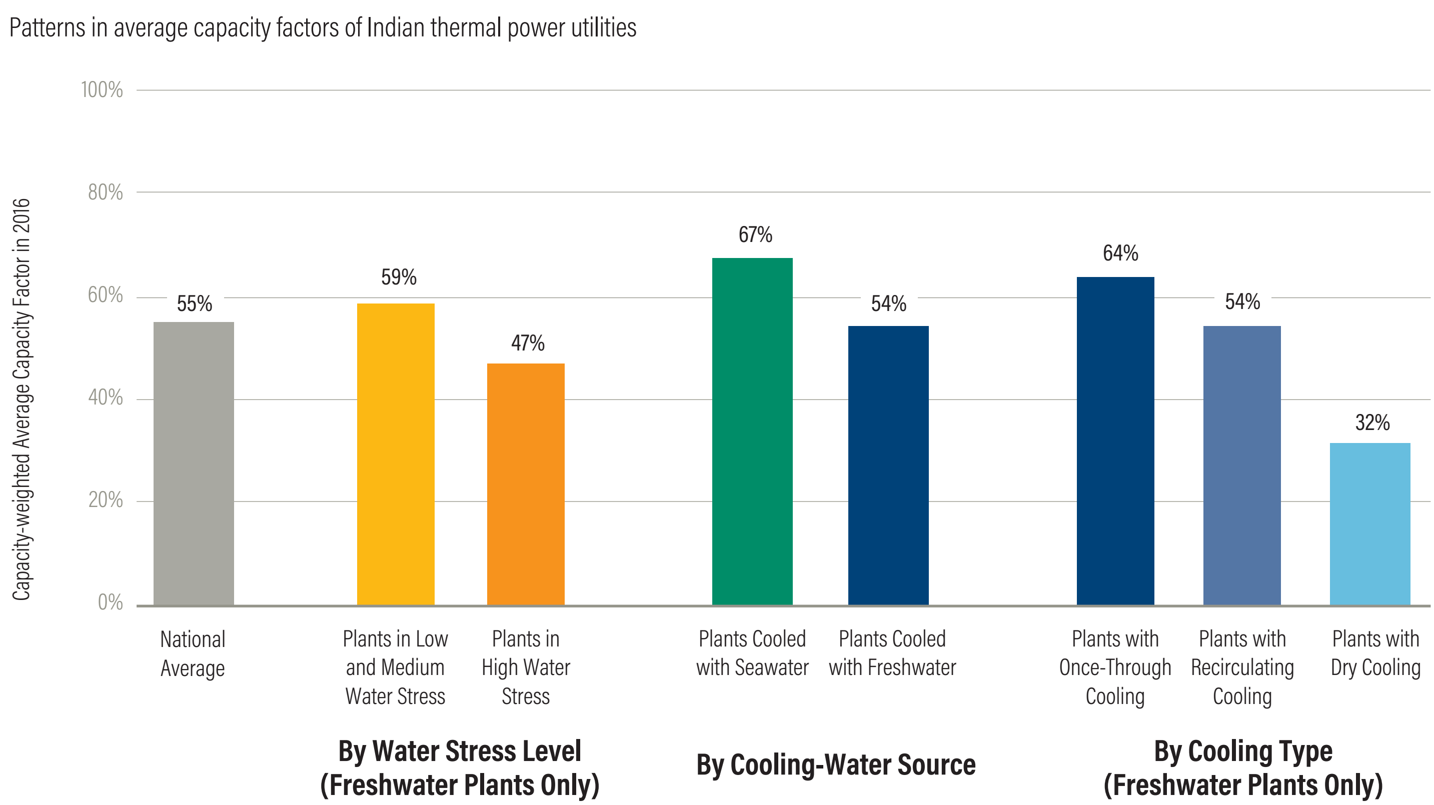
One of the reasons is that, of India's 19 ultra large power plants (with an installed capacity of more than 2GW), 16 are located in low and medium water-stress areas. These megaplants usually have higher capacity factors compared to smaller ones and account for more than 27 percent of the country's total thermal capacity.

We further controlled our comparison analysis by unit age, plant size, and fuel type. The same trends—plants in low and medium water-stress areas had a higher average capacity factor than the ones in high-stress areas—were observed in almost every group when we controlled our analysis by unit age, plant size, and fuel type. The differences in percentage points ranged from 2 to 38, with a median value of 6. Details on the controlled analyses can be found in the appendix.

This indicates that water stress is indeed a limiting factor for India's thermal electricity generation.

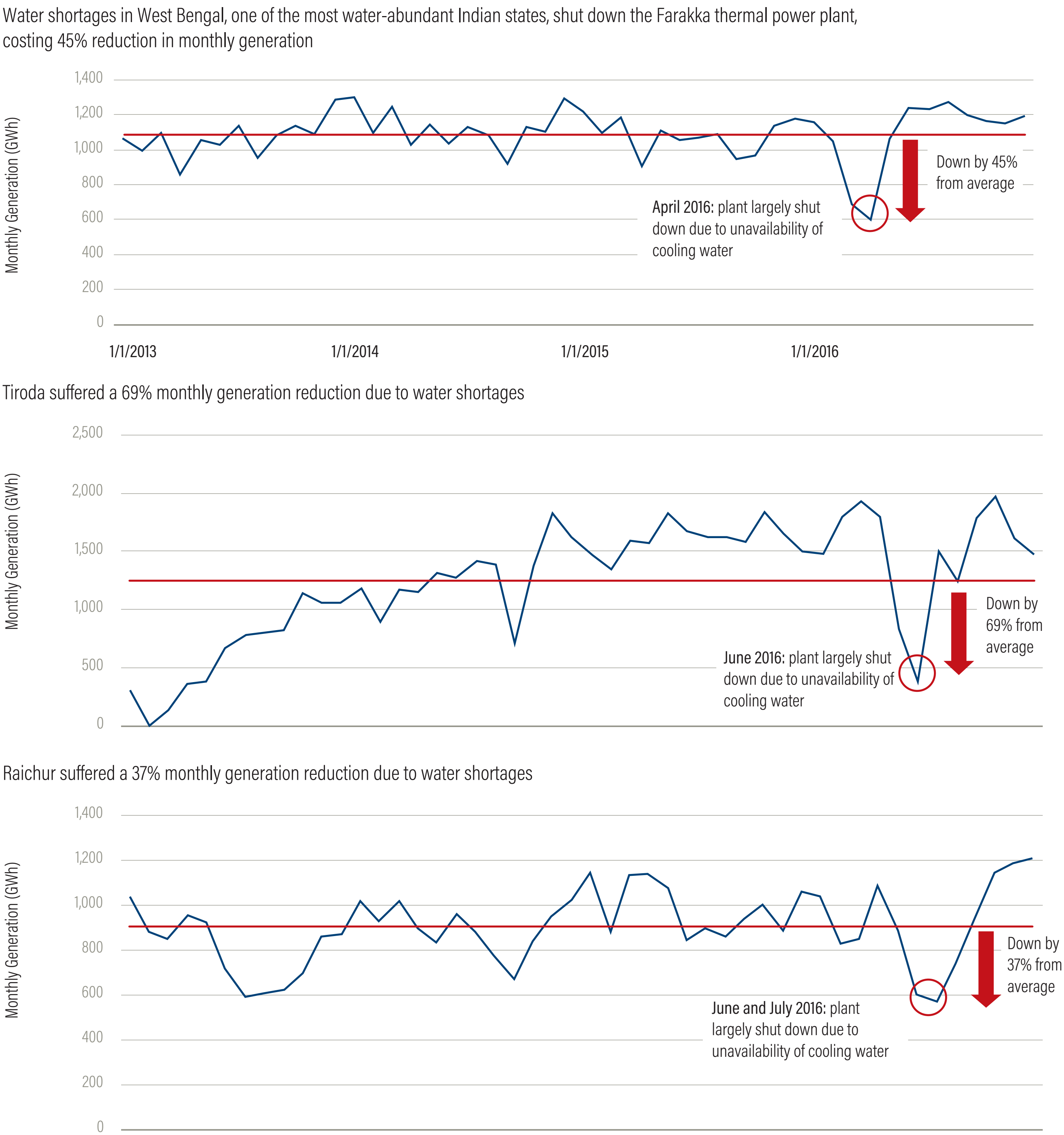
Water users in regions with high water stress are more vulnerable and sensitive to increases in water demand and decreases in water supply, as are thermal utilities. Additionally, for companies that use large amounts of water for production or operation, reputational risks tend to be higher in stressed regions, and regulatory changes could be more uncertain, particularly when competing with domestic users and farmers.

Figure 12 | **National Average Capacity Factors by Exposure to Water Stress, Cooling Water Source, and Cooling Technology in 2016**



Note: "Low and medium water stress" includes low, low to medium, and medium to high water-stress categories from WRI Aqueduct data. "High water stress" includes both high and extremely high.
Source: WRI authors.

Figure 13 | Farakka, Tiroda, and Raichur's Monthly Generation from January 2013 through December 2016



Source: Data from CEA, compiled and analyzed by WRI authors.

Some of the most disruptive water shortages occurred in India's most water-abundant areas.

However, even in water-abundant or low water-stress regions, thermal power plants face water quantity–related risks. Figure 13 shows monthly generation for three thermal plants—Farakka, Tiroda, and Raichur—that are located in either water-abundant or low water-stress areas. However, all three plants have experienced significant, if not the biggest, disruptions in production caused purely by water shortages in recent years.

In April 2016, NTPC's Farakka Super Thermal Power Station in West Bengal, one of India's most water-abundant states, lost about 45 percent of its generation, hundreds of gigawatt hours, compared to its average monthly generation. That was by far the biggest disruption in generation Farakka has seen since 2013.
Once-through plants like Farakka are particularly more vulnerable to unexpected low water levels caused by droughts or delayed monsoons because these plants require extremely large volumes of water for effective cooling, and there is usually no immediate alternative.

The Tiroda and Raichur power plants are located in low water-stress watersheds and equipped with recirculating cooling towers. They have also suffered major losses in generation because of water shortages, as illustrated in Figure 13. Tiroda lost about 69 percent of its generation in June 2016, compared to its average monthly production; and Raichur lost around 37 percent of its generation in both June and July of that year. Both cases are among the most extreme losses for the two plants in recent years.

More than 70 percent of India's existing thermal utilities are likely to experience an increased level of water competition from agricultural, urban, and other industrial demands by 2030.

Additionally, competition for available water will only increase in the coming decades. India's economy has been growing tremendously over the past decade and is projected to more than double in size by 2030 (PwC 2017). Improved living standards, a growing population, and increased demand for food and energy all entail more water demand and consumption, which will pose real threats to society if not managed well. In 2015, WRI Aqueduct's research (Luck et al. 2015) on future projections for water supply, demand, and stress has shown that, for much of the world, water stress will likely increase by 2030, primarily driven by an increase in water demand rather than decreased supply. This is particularly true in developing countries like India, although the country also is projected to experience changes in rainfall amounts and timing due to climate change impacts.

Using Aqueduct's future water supply-and-demand scenarios (based on IPCC 5th Assessment data), we assessed for each power plant what future water-use competition could look like in the watershed of its location under the business-as-usual scenario (Luck et al. 2015). As illustrated in Figure 14, about one-third of India's existing thermal utilities are likely to experience a 20 percent or higher increase in water competition due to rising water demand from other local users. Particularly in the east, northeast, and west of the country, almost all plants are likely to see increased competition in freshwater uses, which may make it more difficult to access the freshwater volumes needed for cooling.

If no additional supply is available, an increased water demand indicates higher water stress and lower buffering capacity in dry periods, both of which could potentially cause more water shortage–related disruptions to thermal generation.

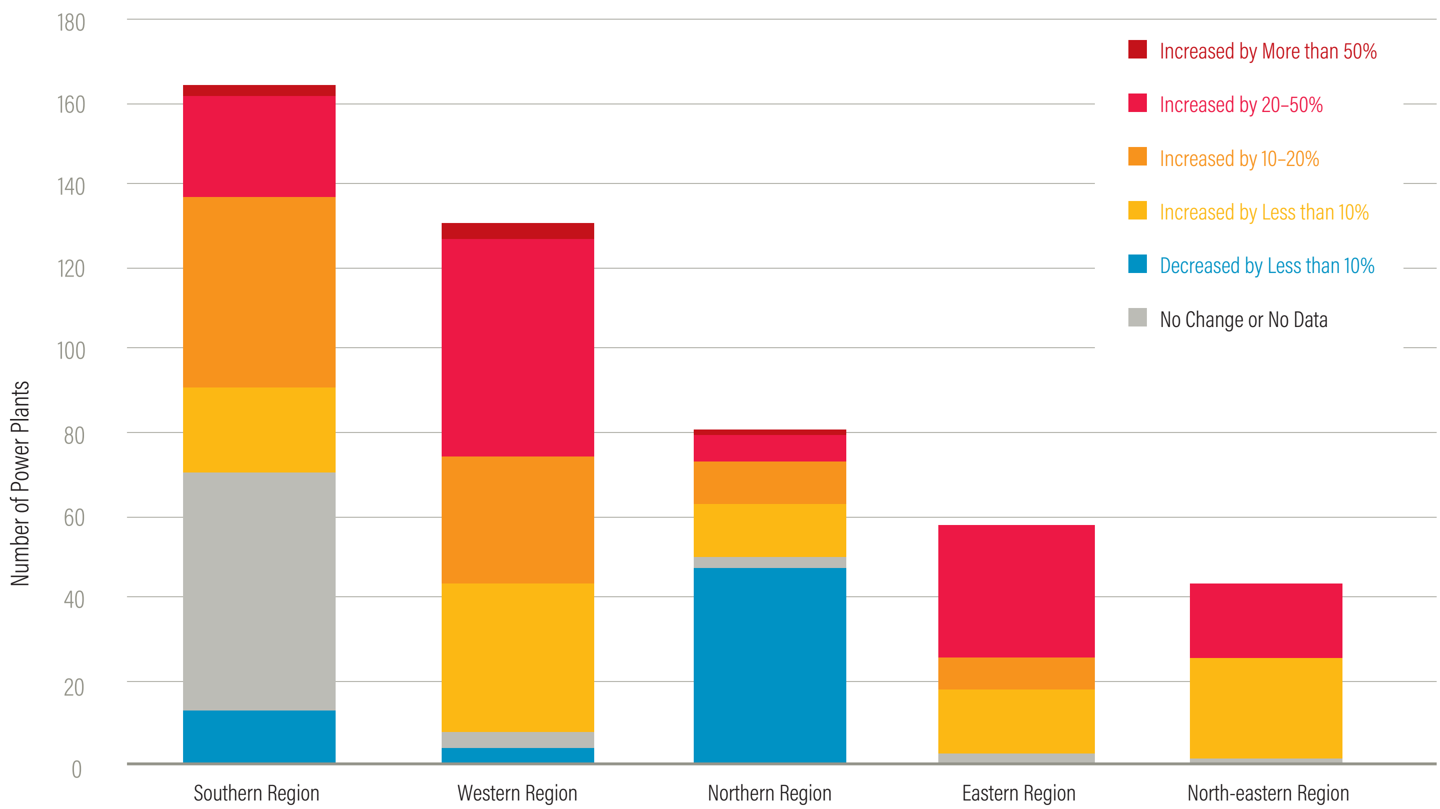
Fourteen of India's 20 largest thermal utility companies experienced water shortage–induced power plant shutdowns at least once between 2013 and 2016.

Using asset-level data (e.g., water intensity, actual generation, and others) and ownership information from Platts, we were able to aggregate plant-level assessments to the corporation level and to evaluate and benchmark water-related metrics along with other performance indicators for Indian utility companies and owners. We believe this exercise can provide value for environment, social, and governance (ESG) research conducted by financial institutions and investors and can help promote transparency and accountability for the power sector in India.

To understand and quantify power company water-related risks, three things need to be measured: water dependency, water risk exposure, and management response. In the context of India, water shortages have long been the primary water-related threat to business continuity for the thermal power generation industry. Therefore, here we focus on identifying long-term chronic water stress–related risks.

Figure 14 | **Projected Changes in 2030 of Competition for Water from Other Sectors Faced by Power Plants within Watersheds**

More than 70% of India's existing thermal utilities are likely to experience an increased level of water competition from other users in the same watershed by 2030



Distributions of Number of Plants by Projected Changes in 2030 in Local Water Competition by Region

Sources : World Resources Institute analysis; CEA (2017); Platts (2016).

We measured water dependency by estimating a corporation's portfolio-level water withdrawal intensity: the ratio of total freshwater withdrawal over total electricity generated across all assets. **To evaluate exposure, we measured three things:**

- Historical water shortage–induced shutdown records
- Percentage of revenue generated by freshwater-cooled plants located in high water-stress areas
- Projected future increase in water competition at the portfolio level

Gauging management response to increased risk of water stress is extremely complex, so we did not attempt to measure this at the national scale.

Table 3 lists values of all four metrics for the 20 largest thermal utility owners in India. In total, they represented more than 70 percent of India's total thermal capacity in 2016.

Fourteen of the 20 largest companies experienced water shortage-induced shutdowns at least once between 2013 and 2016. The other six companies include Damodar Valley, Tata, Nuclear Power Corporation, West Bengal Power, Haryana Power, and Torrent.

Adani Power and Tata Group are in the top 25 percent tier in three of the four metrics, while NTPC, MSEB, and Gujarat State Electricity Corporation. were in the bottom 25 percent tier in two of the metrics.

Table 3 | **Water Dependency and Risk Exposure Indicators for the Top 20 Largest Thermal Utility Owners in India as of December 2016**

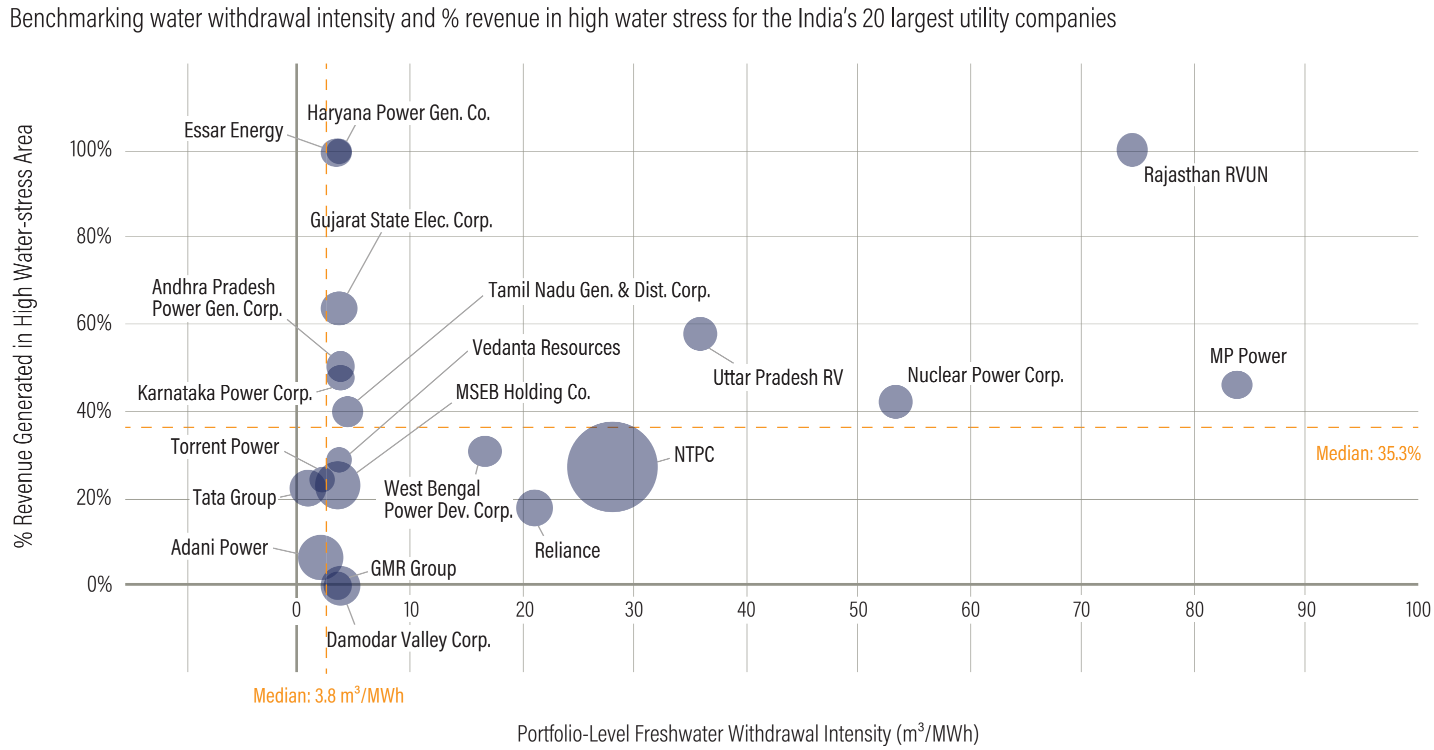
COMPANY	TOTAL THERMAL CAPACITY (GW)	FRESHWATER WITHDRAWAL INTENSITY (M^3/MWH)	NO. OF ASSETS THAT HAD AT LEAST ONE WATER SHORTAGE–INDUCED SHUTDOWN RECORDED BETWEEN 2013 AND 2016	% REVENUE GENERATED IN HIGH WATER-STRESS AREA	PROJECTED CHANGE IN FUTURE WATER-USE COMPETITION WITH OTHER WATERSHED STAKEHOLDERS
NTPC	40.8	28.1	3	27.2%	9.9%
Adani Power	11.0	2.0	2	6.3%	3.0%
MSEB Holding Co.	10.5	3.5	3	23.0%	27.7%
Damodar Valley Corp.	7.3	3.8	0	0.0%	21.0%
Reliance	6.8	21.1	1	18.1%	13.8%
Tata Group	6.4	0.9	0	22.3%	14.2%
Gujarat State Elec. Corp.	6.0	3.7	1	63.4%	23.1%
Nuclear Power Corp.	5.7	53.3	0	42.4%	10.4%
Uttar Pradesh RV	5.5	35.9	1	57.7%	8.1%
Tamil Nadu Gen. & Dist. Corp.	5.3	4.5	2	40.1%	5.7%
Rajasthan RVUN	5.2	74.4	2	100.0%	5.8%
West Bengal Power Dev. Corp.	4.9	16.7	0	30.6%	8.2%
Andhra Pradesh Power Gen. Corp.	4.5	3.8	1	50.2%	5.9%
MP Power	4.3	83.8	2	46.0%	11.5%
Essar Energy	4.3	3.5	1	99.4%	13.7%
GMR Group	3.7	3.6	1	0.0%	15.3%
Karnataka Power Corp.	3.6	3.8	2	47.7%	15.8%
Haryana Power Gen Co.	3.3	3.8	0	100.0%	-5.2%
Vedanta Resources	3.2	3.6	2	29.1%	9.0%
Torrent Power	3.2	2.2	0	24.3%	18.5%

Top 25% | Upper middle 25% | Lower middle 25% | Bottom 25%

Notes: Capacity data are from Platts and might have small discrepancies compared to data disclosed by CEA or other sources. Ownership information is obtained from Platts using the "parent company" attribute in the database, which includes subsidiaries but not joint ventures. Thermal capacity includes all operating thermal units (captive plants excluded) as of December 2016 based on Platts. Water withdrawal intensity is the ratio of total freshwater withdrawal over total thermal generation in 2016. The number of plants with water shortage–induced shutdowns history only covers 4 years between January 2013 and December 2016. Plant-level fiscal year revenue is calculated at the plant level using a plant-specific rate of sale of power and actual generation disclosed by CEA for 2016. All seawater-cooled plants are assumed to have zero exposure to water stress. Projected change in future water-use competition is weighted by capacity factor, and all seawater-cooled plants are assigned with zero change in future freshwater competition.

Source: WRI authors.

Figure 15 | **Benchmarking Portfolio-Level Freshwater Withdrawal Intensity and % Thermal Power Generation Revenue in High Water-Stress Areas in 2016 for India's 20 Largest Utility Companies**



Notes: Seawater-cooled plants all have a water-stress score of zero because they are not subject to freshwater scarcity. Portfolio-level freshwater withdrawal intensity is the ratio of total freshwater withdrawal over total thermal generation in 2016. Bubble size denotes a company's total thermal installed capacity in 2016.

Source: WRI authors.

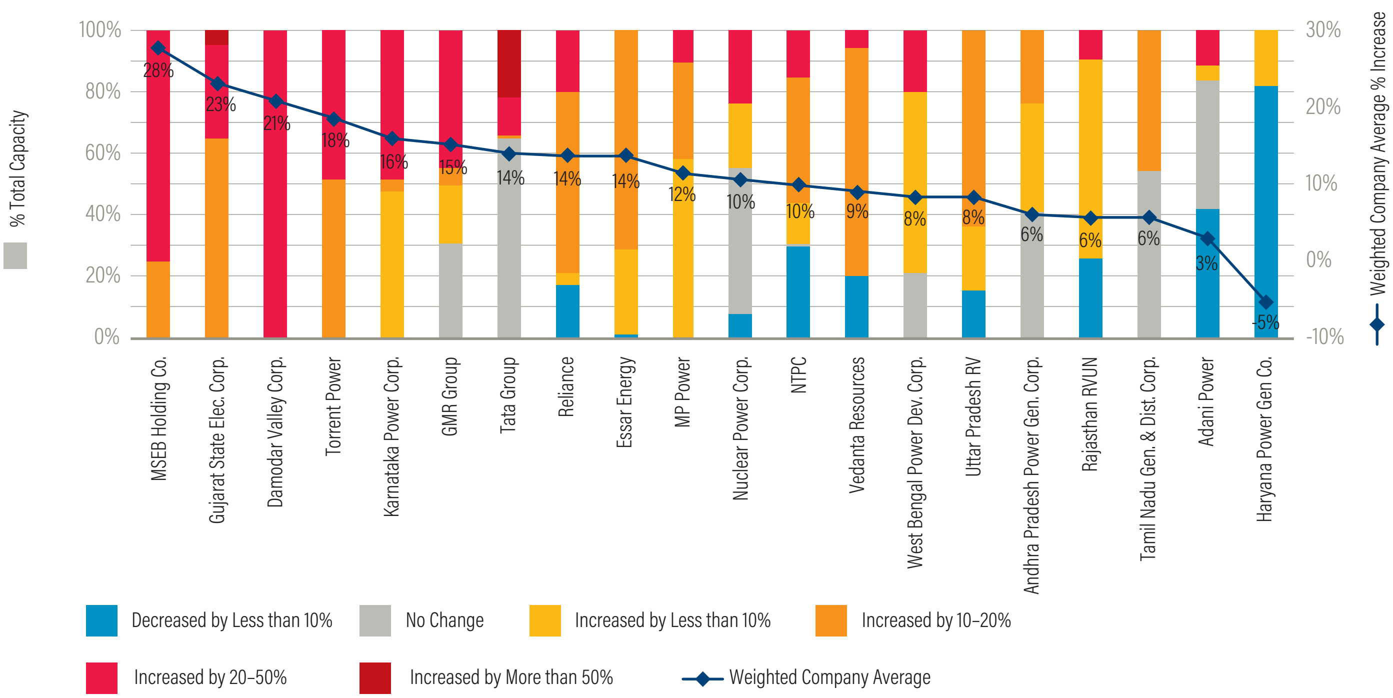
We benchmarked, at the portfolio level, freshwater withdrawal intensity and percentage revenue generated in the high-stress area for the 20 utility owners in Figure 15. Overall, most companies with high water-withdrawal intensity have relatively low exposure to water stress. This is because in areas of obvious high water stress, companies are likely to already have taken steps, such as changing cooling technologies, to reduce their exposure in water-stressed regions.

Companies that have a higher exposure to water stress typically have a relatively low water-withdrawal intensity, except for Uttar Pradesh RV and Rajasthan RVUN, Nuclear Power Corporation, and MP Power. However, the intensity levels across companies vary greatly. For example, at the portfolio level, MP Power needs roughly 84 cubic meters of freshwater to generate 1 MWh of electricity, while Tata Group needs less than 1 cubic meter. High withdrawal intensities are driven by power plants' use of once-through cooling systems, which are largely concentrated in low to medium water-stress regions. Low withdrawal intensities are mostly driven by the use of dry or seawater cooling systems.

For each utility owned by these 20 companies, we assessed the projected change in total water demand in the watershed of the utility's location. Figure 16 illustrates for each company how much of its capacity is likely going to see an increase in future water-use competition and by how much. Nineteen out of the 20 companies are likely to see an average increase in water-use competition between 3 percent and 28 percent.

Figure 16 | **The Level of Increase in Water-Use Competition in Capacity and Weighted Portfolio-Level Average Increase for the Top 20 Largest Indian Thermal Utility Owners**

By 2030, almost all companies will see an increase in water-use competition between their utility assets and other water users in their shared watershed



Notes: Seawater-cooled capacity is included in the "No Change" category because these plants are not subject to freshwater scarcity. Company portfolio-level average increases are weighted by plant capacity.

Source: WRI authors.

The 14 companies together lost over $1.4 billion in potential power sale revenue due to water shortages between 2013 and 2016.

Leveraging CEA's daily outage data, we further analyzed the potential losses in revenue from sale of power for each of the 24 plants that were owned by the 14 companies and had water shortage–induced shutdown records between 2013 and 2016.

As shown in Table 4, the 24 plants together lost more than $1.4 billion in potential revenue over the four years between 2013 and 2016. Additionally, the nine companies that had shutdown records in 2016 lost over $614 million in potential revenue, accounting for about 2.3 percent of their total revenue from the sale of power in 2016.

Table 4 | **By Plant Water Shortage-Induced Outages and Associated Potential Losses in Power Sale Revenue**

COMPANY	PLANT	RATE OF SALE OF POWER (PAISE/ KWH)	OUTAGE (MW*DAY)				POTENTIAL LOSSES IN REVENUE FROM SALE OF POWER ($1,000)			
			2013	2014	2015	2016	2013	2014	2015	2016
Adani Power	Tirora TPS	255.00	2,640			89,100	2,310			77,948
	Udupi TPP	468.00			28,200	1,200			45,277	1,927
Andhra Pradesh Power Gen. Corp.	Rayalaseema TPS	398.20	210				287			
Essar Energy	Salaya TPP*	528.64	19,200	7,200	37,200	5,400	34,821	13,058	67,466	9,793
GMR Group	EMCO Warora TPS*	316.47			1,800	23,700			1,954	25,731
Gujarat State Elec. Corp.	Sikka Rep. TPS	542.00			750				1,395	
Karnataka Power Corp.	Bellary TPS	402.36				3,500				4,831
	Raichur TPS	384.06			210	17,010			277	22,412
MP Power	Satpura TPS	306.00	5,500	12,500			5,774	13,123		
	Shri Singhaji TPP*	283.89			600				584	
MSEB Holding Co.	Bhusawal TPS	319.00	210				230			
	Koradi TPS	405.00		420				584		
	Parli TPS	337.00	220,740	105,750	208,880	334,760	255,210	122,263	241,498	387,035
NTPC	Barh II	564.00			1,980				3,831	
	Farakka STPS	374.00				16,900				21,684
	Rihand STPS	245.00		3,500				2,942		
Rajasthan RVUN	Giral TPS	286.77	1,125				1,107			
	Kota TPS	337.15	420				486			
Reliance	Sasan UMTPP*	283.89		1,320	660	2,640		1,286	643	2,571
Tamil Nadu Gen. & Dist. Corp.	Ennore TPS	523.12		440				790		
	North Chennai TPS	523.12	1,200	1,200		600	2,154	2,154		1,077
Uttar Pradesh RV	Harduaganj TPS	546.97	1,800				3,378			
Vedanta Resources	Sterlite TPP*	246.00				45,000				37,978
	Talwandi Sabo TPP*	246.00				25,080				21,166

Notes: Rates of sale of power are from CEA. However, for plants marked with an asterisk, the rate of sale of power was estimated based on state or company averages due to data availability. The U.S. dollar to Indian rupee exchange rate is 69.956, the 2016 yearly average from the U.S. Internal Revenue Service. Details on the potential revenue loss calculation can be found in the appendix.

Source: Data from CEA, compiled and analyzed by WRI authors.

Opportunities

As demonstrated, India's current power sector is extremely dependent on freshwater resources, exposed to water shortage-related risks like water stress and drought, and has been suffering from disruptions in accessing cooling water, resulting in generation and financial losses.

As the country develops, competition for freshwater resources will only grow, and climate change is likely to cause more disruption to predictable supply (Mazdiyasni et al. 2017). If business-as-usual continues, power plants will only face more challenges in accessing water and become more vulnerable to water shortage–related risks.

There are ways to reduce such risks by upgrading cooling systems, improving plant efficiency, and, ultimately, shifting toward water-independent renewables like solar PV and wind.

UPGRADING COOLING SYSTEMS

The most common cooling technology advancement includes replacing once-through with recirculating cooling technology, adopting dry or hybrid cooling in high water-stress regions, and switching to alternative cooling-water sources like seawater and wastewater when appropriate. Some even more advanced cooling technologies include dew point cooling, thermosyphon systems, vapor recovery systems, and others (EPRI 2013). Most of these techniques can effectively reduce freshwater dependency (withdrawal intensity) but cannot eliminate it or exposure to freshwater scarcity (except for seawater cooling technologies). Some of these techniques might actually increase water consumption.

IMPROVING PLANT EFFICIENCY

Improving plant efficiency can indirectly reduce water withdrawal and consumption intensity. The more efficient a plant is, the more electricity it can generate using the same amount of cooling water. For example, generator replacement and heat transfer coating are two examples of efficiency improvements that can increase kWh per cubic liter of cooling water. While these improvements can reduce water intensity to a certain degree, they cannot mitigate water shortage–related risks entirely for power plants.

SHIFTING TOWARD RENEWABLES

Generating power with solar PV and wind can achieve not only zero carbon emissions but also near-zero water consumption. At the national level, moving toward a power mix that has a higher share of PV and wind can reduce the power sector's water intensity and exposure to risks. At the local level, these renewables could help improve the resiliency of the local power system to extreme drought events and, at the same time, save freshwater for domestic and agricultural users.

India has already been developing effective plans along these lines. Both MOEFCC's proposal on power plant water withdrawal limits (listed in Table 5) and the "40/60" renewable energy development plan (MOEFCC 2015a) are good examples. We evaluated and quantified how these regulations and plans, if successfully implemented, would likely affect power sector freshwater withdrawal and consumption in India in 10 years.

Table 5 | **Three Draft Regulations on Water Withdrawal Intensity Notified by MOEFCC of India**

NO.	MOEFCC WATER NORMS FOR THERMAL POWER PLANTS
1	All plants with once-through cooling (OTC) shall install cooling tower (CT) and achieve specific water consumption of 3.5 m^3/MWh within two years of notification.
2	All existing CT based plants shall reduce specific water consumption up to maximum of 3.5 m^3/MWh within a period of two years of notification.
3	New plants to be installed after January 1, 2017, shall have to meet specific water consumption of 2.5 m^3/MWh and achieve zero water discharge.

Notes: WRI authors think "specific water consumption" is the same as WRI's definition of water withdrawal. Also, "thermal power plants" here, in this notification only, include fossil fuel plants, not nuclear or CSP plants.

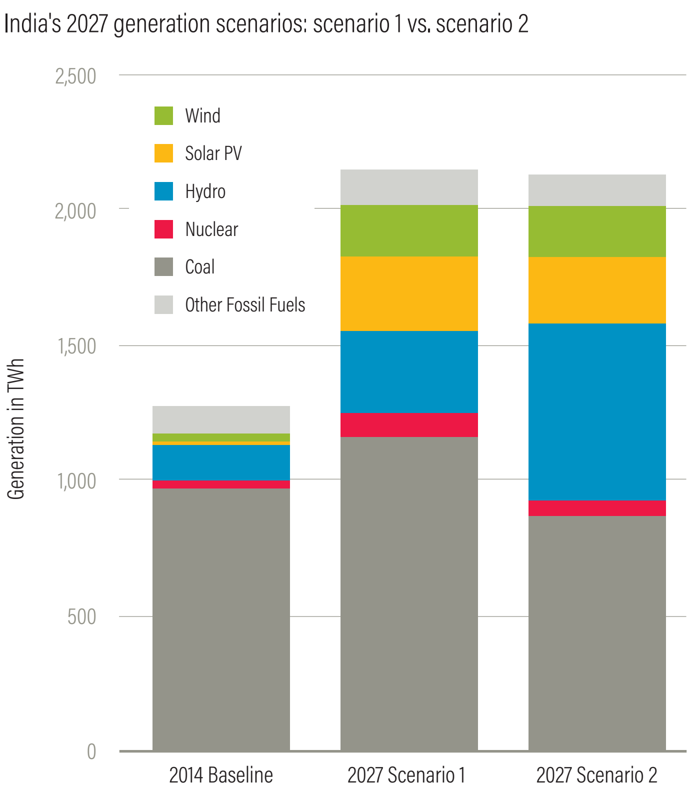
Source: CEA (2016).

One thing worth noting is that we think the term "specific water consumption" in MOEFCC's notified regulations is the same as our definition of water withdrawal. The same judgment was also made in Chaturvedi et al. (2017). WRI authors learned from Indian power companies that only water withdrawn from the water intake is measured, and there is no measurement of water consumption for India's power plants, which is also confirmed in Chaturvedi et al. (2017).

For India's power sector, excluding hydro, water withdrawal and consumption intensities would drop significantly by 2027 under scenario 2.

To evaluate future power sector water demand, projections on future power mix and generation are needed, as well as future power sector cooling technology distribution and water intensity factors. For energy projections, we used two scenarios: scenario 1, developed by CEA and shared with WRI authors, and scenario 2, developed by WRI authors based on our interpretation of and assumptions in the Draft National Electricity Plan (CEA 2016). For cooling distribution and water factors, we used the MOEFCC notified regulations, assuming they were 100 percent implemented. In order to capture the shifts in power mix, this analysis covers the entire Indian power sector (except for hydro). More details on methods may be found in IRENA (2018).

Figure 17 | **India's 2014 Baseline Generation and Projections for 2027 under Two Scenarios, Scenario 1 and Scenario 2**



Sources: CEA and WRI authors.

Figure 17 illustrates the baseline and projected power generation by fuel type under two selected scenarios developed by CEA. The two scenarios have roughly the same total generation of 2,140 TWh for the year 2027, a 68 percent increase compared to 2014. The share of PV and wind between the two scenarios is also almost the same.

It is worth noting that electricity not generated by fossil fuels accounts for 40 percent of the total generation under scenario 1, and 54 percent under scenario 2. Both scenarios are more ambitious than India's Nationally Determined Contribution in which the country commits to 40 percent non-fossil-fuel installed capacity, which translates to roughly 26–30 percent generation, according to Climate Action Tracker. Based on the energy scenarios and cooling and water-related projections, our model indicates that both the water withdrawal and consumption intensities of the Indian power sector, excluding hydro, would drop significantly by 2027 under both scenarios, compared to the 2014 baseline.

Figures 18 and 19 illustrate the reduction in water withdrawal and consumption intensity under each CEA scenario as well as the key drivers and each of their contributions to the reduction. Under scenario 1, withdrawal intensity would decrease by almost 71 percent. About 73 percent of that reduction would be driven by cooling advancement. The consumption intensity would decrease roughly by 22 percent with about 96 percent of that reduction driven by the power mix shift.

Under scenario 2, withdrawal intensity would decrease by 76 percent. About 65 percent of that reduction would be driven by cooling advancement. The consumption intensity would decrease by about 25 percent. Almost 98 percent of that reduction would be driven by the power mix shift. In both scenarios, while cooling technology advancement reduces withdrawal intensity, it actually increases water consumption intensity because recirculating towers consume more water to generate power compared to once-through systems.

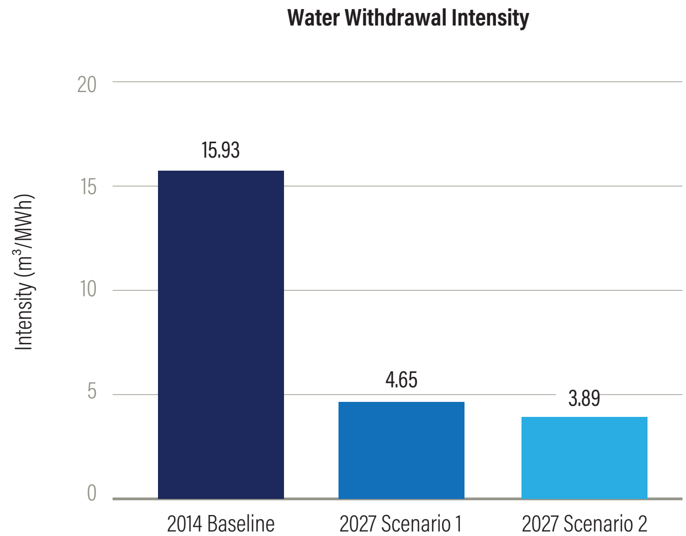
Freshwater consumption of India's thermal power sector would stay below its 2016 level by 2027 if the country's most ambitious renewable targets are achieved and the notified stringent water regulations implemented.

Additionally, we found a reduction of 9.6 billion cubic meters in total water withdrawal under scenario 1. However, it comes with an increase of 622 million cubic meters in water consumption. Under scenario 2, both withdrawal and consumption would decrease by 12.4 billion cubic meters and 52 million cubic meters, respectively.

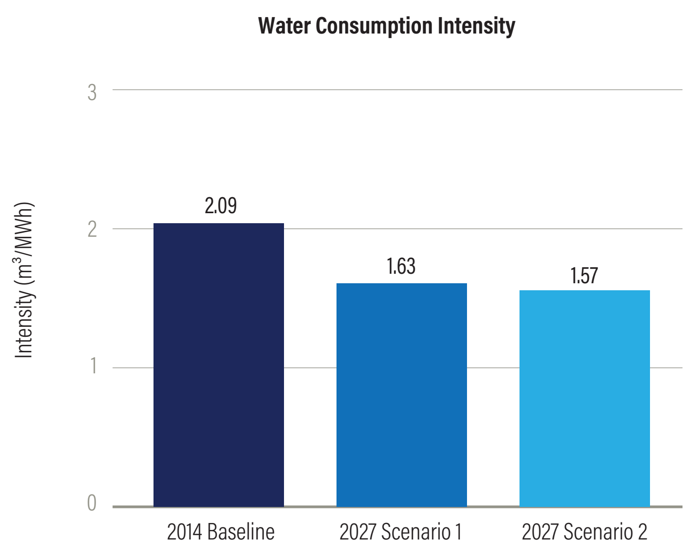
Overall, cooling advancement could significantly reduce the Indian power sector's dependency on freshwater withdrawal but would increase water consumption, which would likely worsen the water-stress condition in certain areas. Plant efficiency enhancement could contribute to reduction in both water withdrawal and consumption, but only by a small degree. Shifting toward more solar PV and wind in India's power mix could reduce both withdrawal and consumption significantly and improve the power sector's resiliency to extreme drought events and sustainability.

Figure 18 | **India's Power Sector Freshwater Withdrawal and Consumption Intensities for Baseline and Projections (Hydro Excluded)**

Water withdrawal intensity would decrease by as much as 76% under Scenario 2.

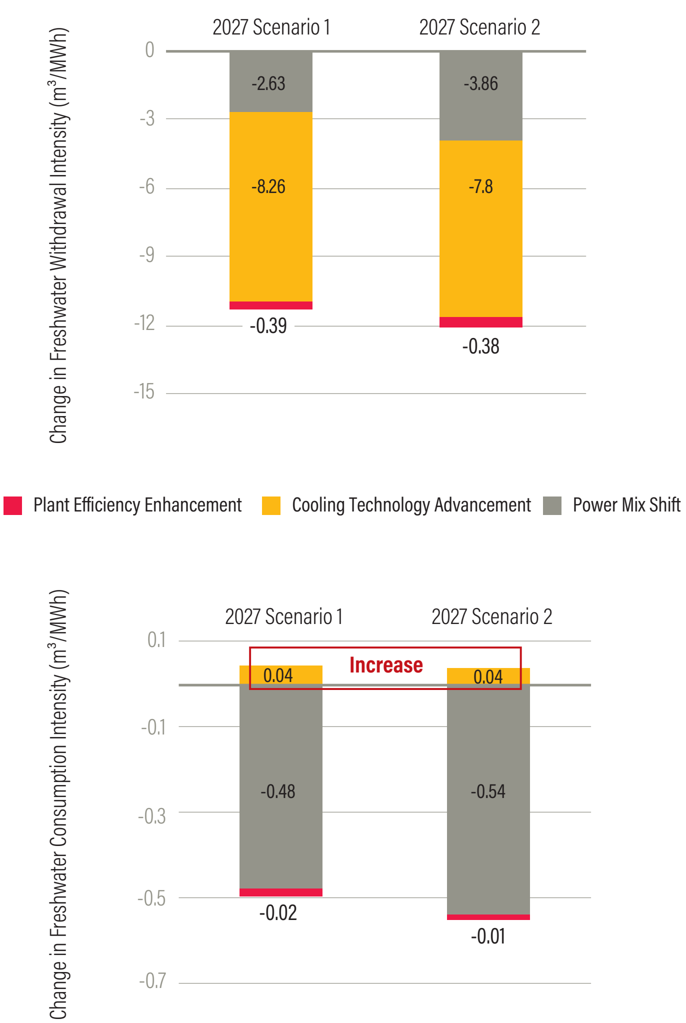


Water consumption intensity would decrease by as much as 25% under Scenario 2.



Sources: WRI authors.

Figure 19 | **Key Drivers and Their Contributions in Intensity Reductions between the 2014 Baseline and Future Projections (Hydro Excluded)**



Sources: WRI authors.

RECOMMENDATIONS

The Ministry of Power, Government of India, should mandate that power plants start monitoring and disclosing water withdrawal and discharge data, leveraging its existing daily reporting system.

Currently, there is significant data gap in power plant water withdrawal and consumption information in India. Unlike the detailed generation and capacity data one can easily find for power plants, water-related data are scarce and difficult to find. As much as our research attempts to fill that gap, due to the limitations of our data and methodology, the results still cannot fully reveal what is actually happening on the ground without monitoring and reporting of actual observed data.

Ultimately, what gets measured, gets managed. The Ministry of Power should mandate that power plants monitor and disclose their water withdrawal and discharge data on a daily basis, leveraging CEA's existing daily reporting system. This will help promote transparency and accountability in how the power sector manages water resources and build the foundation for assessing risks and measuring progress.

Reporting on water data monitoring and disclosure for power plants should be standardized.

Unlike greenhouse gas emissions, there is no widely recognized guideline or standard on how power plants should account for and report on their water usage. Terms like "demand," "use," "withdrawal," and "consumption" that are used to describe water-related activities are often not defined in the same way in the energy sector as they are for water professionals. For example, MOEFCC's notified regulations use the term "specific water consumption" when referring to what is conventionally called water withdrawal.

The lack of standardization of definition and calculation methodologies makes it difficult for utilities to monitor and disclose their water data, thereby discouraging them from reporting and weakening the comparability and usefulness of the data.

A standardized thermal power sector water data reporting method would provide consistency and clarity, help policymakers develop and implement specific water conservation regulations, and guide utility companies in monitoring and disclosing their water performance.

The Ministry of Power, Government of India, should set power sector water performance benchmarking guidelines and create policy guidelines and incentives for better performers.

As our corporate benchmarking analysis shows, portfolio-level water dependency and risk exposure vary greatly between companies. This true for both public and privately owned power companies. Some are more freshwater-efficient and have less environmental impact than others. However, due to data and method limitations, our benchmarking doesn't capture companies' water management practices and technological innovations. Both public and private power utility companies' water performance should be benchmarked with standardized monitored data and corporate disclosure. The Government of India should set benchmarking guidelines on water dependency, exposure to water risks, and industry best practices for water management.

Utilities that are better at managing water and controlling risks have lower chances of disruptions in their services during extreme drought events and should be favored and rewarded for their effort and ability to provide greater stability and more reliable services through regulations and incentives created by the Government of India.

By creating policy incentives for better water management, the Government of India also will help foster a healthy environment to help better performers become more competitive in the market.

Thermal power utility companies should investigate and assess their water-related risks to identify assets at risk and invest in risk mitigation or reduction efforts to ensure business continuity and to prepare for future uncertainty.

In recent years, some Indian power plants have experienced significant, if not the biggest, disruptions in electricity generation, caused purely by water shortages. Thermal utility companies should investigate their water dependency, risk exposure, and management at the asset level across their portfolio. A good understanding of potential risks would help companies develop effective mitigation strategies to ensure long-term business continuity and to better prepare for future uncertainties.

Conducting a portfolio-level assessment of water dependency and risk exposure is the key to understanding risks, prioritizing resources, and informing effective mitigation strategies. Additionally, climate change impacts and economic growth will create additional challenges, making it crucial to reassess watershed hydrology at the individual power plant level, including quantifying potential changes in drought probabilities to inform contingency plans and long-term business development planning.

Adopting advanced cooling technologies can help reduce a utility's dependency on water as well as its impact on downstream users. Additionally, improving plant water-use or power-generation efficiency can reduce plant water withdrawal and consumption per unit of energy generated. For plants that are close to wastewater treatment facilities, using treated wastewater for cooling can reduce or eliminate the immediate freshwater competition with other water users. For coastal thermal utilities, one way to eliminate risks associated with freshwater scarcity is to use seawater as a cooling source in a responsible way.

Public and private sector investors should assess their investment portfolios' exposure to water risks, identify highly exposed companies, and urgently engage those companies to promote better water management practices and reduce such risks.

Fourteen of India's 20 largest thermal utility companies experienced water shortage–induced power plant shutdowns at least once between 2013 and 2016, losing more than $1.4 billion in total in potential revenue from the sale of power. Additionally, these companies are likely to see an increase in water-use competition by 2030 and therefore would continue experiencing water-related disruptions if they continue business as usual.

Investors (including public financial institutions like development banks) should assess their financial exposure to water-related risks for their investment portfolios and leverage this type of research to engage with companies in which they invest, further identifying company strategies to address water scarcity issues and ultimately pushing companies to be more sustainable and socially responsible, thereby benefiting both people and the environment.

The Government of India should keep working toward its ambitious renewable goals and prioritize solar PV and wind projects when possible to scale up power production while reducing the power sector's exposure to water-related risks.

Under scenario 2, by 2027, India's power sector (hydro excluded) would see a 76 percent decrease in water withdrawal intensity. More than 32 percent of that reduction will be driven by the country's power mix shifting toward more solar PV and wind. Water consumption intensity would decrease by about 25 percent; almost 98 percent of that reduction would be driven by the power mix shift.

Compared to cooling technology advancement or plant efficiency enhancement, transitioning to more solar PV and wind generation is the only pathway at scale that can cut back both water withdrawal and consumption while sustaining growth in power generation. This is essential to reducing not only the power sector's water dependency and exposure to water risks, but also its impact on the ecosystem and other water users at the national scale.

The Government of India should keep working toward its ambitious renewable goals and prioritize solar PV and wind projects when possible. These investments would help offer consumers more reliable access to electricity and almost zero water consumption and carbon emissions, which, at the same time, would contribute to meeting multiple Sustainable Development Goals (SDG), for example, SDGs 6, 7, and 13.

LIMITATIONS

This study focuses on assessing the Indian thermal power sector's water usage, water quantity–related risks, specifically water scarcity, and opportunities associated with withdrawal and consumption reduction and conservation. However, another main water challenge for the power sector is the quality of its discharge water, like thermal and metal pollution, which we didn't examine. Further research on quality issues could help provide a more comprehensive understanding of the power sector's water risks.

Hydropower plants are entirely dependent on freshwater and have also been suffering from drought and water shortages in recent years. Judging by CEA's 2027 power mix scenarios, India has great ambitions to achieve more generation from its hydro sector. Research around future changes in water availability and supply variability in the context of hydropower generation in India would provide useful information to inform decision-making in hydro sector development.

The methodologies we used in this study for developing all the water data have certain assumptions baked in and therefore have introduced uncertainties into our estimates. For example, we used median values of water withdrawal and consumption factors for each cooling and fuel type. While this approach is sufficient for portfolio-level analysis, it cannot differentiate between plants within the same cooling and fuel type group based on a plant's generation efficiency.

Additionally, the method we used in estimating water uses does not perform well in cases where power plants have hybrid cooling systems because there is no obvious way to determine for a utility how much generation is cooled by one cooling system versus the other.

The data challenges described above can only be addressed by more transparency and accountability from the power sector. With this research, we aim to demonstrate how leaders could make better-informed decisions in the power sector by tracking and analyzing water data. We hope that this will help promote a more sustainable future for all.

APPENDIX

1. Indian Specific Water Withdrawal and Consumption Factors

We use Indian specific water withdrawal and consumption factors when available. Table A1 lists the specific values we used for each fuel cooling type in this study. Chaturvedi et al. (2017) and Bhattacharya and Mitra. (2013) provide factors based on reports or surveys of Indian power plants, which were used for most of the categories in our analysis. CWR/IRENA (2016) provides factors based on Chinese plants, and Macknick (2012) provides factors that are summarized from U.S. data.

2. Missing Data Imputation

There are some plants for which we could not identify cooling and source water type because they could not be geolocated. For those plants, we use a data imputation approach based on random forests (R's missForest package). The algorithm predicts a plant's cooling, source water, and capacity factors using a classification scheme based on characteristics associated with similar plants.

As shown in Table A2, our model's out-of-bag (OOB) error is low, which is valid if plants with missing data are not systematically different from plants without missing data. Observations that are not bagged in the training data set are referred to as OOB observations (Gareth et al. 2017). The missForest package computes OOB mean-squared errors for numeric variables, and proportion of falsely classified objects for categorical variables (Stekhoven 2013). Overall, the normalized root-mean-square error for numeric variables

Table A1 | **Indian Specific Water Withdrawal and Consumption Factors**

FUEL COOLING	WITHDRAWAL (M^3/MWh)			CONSUMPTION (M^3/MWh)			SOURCE
	MIN	MEDIAN	MAX	MIN	MEDIAN	MAX	
Biomass—dry	0.13	0.13	0.13	0.13	0.13	0.13	Macknick (2012)
Biomass—recirculating	1.89	3.32	5.53	1.82	2.09	3.65	Macknick (2012)
Coal—dry	0.31	0.31	0.31	0.31	0.31	0.31	CWR/IRENA (2016)
Coal—once-through	171.00	216.00	261.00	0.86	1.56	1.64	Chaturvedi et al. (2017)
Coal—recirculating	2.31	3.79	5.16	2.19	2.59	4.80	Chaturvedi et al. (2017)
Gas—dry	0.06	0.06	0.06	0.06	0.06	0.06	Bhattacharya and Mitra (2013)
Gas—recirculating	1.24	1.62	2.00	0.86	1.17	1.60	Chaturvedi et al. (2017)
Nuclear—once-through	196.20	242.71	289.22	0.78	1.45	1.91	Chaturvedi et al. (2017)
Nuclear—recirculating	6.42	6.42	6.42	3.82	3.82	3.82	Chaturvedi et al. (2017)
Oil—dry	0.06	0.06	0.06	0.06	0.06	0.06	Bhattacharya and Mitra (2013)
Oil—recirculating	1.24	1.62	2.00	0.86	1.17	1.60	Chaturvedi et al. (2017)
Other—recirculating	2.31	3.79	5.16	2.19	2.59	4.80	Chaturvedi et al. (2017)
Solar—recirculating	2.45	2.68	3.10	2.45	2.67	3.10	Chaturvedi et al. (2017)
Other—dry	0.31	0.31	0.31	0.31	0.31	0.31	CWR/IRENA (2016)

Note: Data for "Other—recirculating" and "Other—dry" were taken from "Coal—recirculating" and "Coal—dry," respectively.

in our model is around 0.002, much closer to 0 (indicating a good fit) than 1 (indicating a bad fit). Imputation used the following variables: installed capacity, year, fuel type, state, capacity factors, source water, cooling type, latitude and longitude, distance to coastline, water stress, water supply seasonal variability, drought severity, and business type.

Table A2 | **Data Imputation Out-of-Bag Errors**

VARIABLE	TYPE	OUT-OF-BAG ERROR	
		MEAN-SQUARED ERRORS	PROPORTION OF FALSELY CLASSIFIED
Capacity factor in 2016	Numerical values	0.002	N/A
Source water type	Categorical values	N/A	0.002
Cooling type	Categorical values	N/A	0.020

3. Water Shortage–Induced Losses by Month by State between 2013 and 2016

Table A3 lists all water shortage–induced losses in potential power generation by month by state between 2013 and 2016.

4. Capacity Factor Analysis and Comparison Controlled by Unit Age and Plant Size

To ensure that the capacity factor trends we observed were not systematically biased by those factors, we further analyzed plant size and age distributions within each water-stress category and repeated the same capacity factor comparison by water stress for each size and age group as well as by fuel type.

According to Platts, as of December 2016, new units installed between 2006 and 2016 account for 61.5 percent of India's total thermal installed capacity. Plant age distributions are similar between high-stress and low-and medium-stress regions. For high water-stress regions, 65.6 percent of the total thermal capacity was installed between 2006 and 2016, and for the capacity in low and medium water-stress regions, that number is 59.8 percent.

Table A3 | **Total Water Shortage-Induced Losses in Potential Electricity Generation (GWh) between 2013 and 2016 by Month by State**

SOURCE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
All India	1,315	1,453	2,019	2,776	3,442	3,438	3,115	4,021	2,873	2,245	1,695	1,256
Maharashtra	1,279	1,325	1,843	1,887	3,076	2,934	2,252	2,942	2,165	1,651	1,254	1,093
Gujarat			14	446	115	58	187	58	389	343	29	29
Karnataka		25	116	29	30	141	96	547	219			
Orissa						101	461	418	101			
Punjab										190	412	
Madhya Pradesh	36	55	45	44	158	57	42	11				63
West Bengal		36		370			42					
Chhattisgarh						121	35	6				
Uttar Pradesh					36	7						60
Tamil Nadu						14		39		29		
Rajasthan					27	5						
Bihar										32		
Andhra Pradesh		12										11

Table A4 | **Average Capacity Factors Comparison of Plants in Low and Medium Water-Stress Areas and High Water-Stress Regions by Control Group**

CONTROL FACTOR	CONTROL GROUP	AVERAGE CAPACITY FACTOR OF PLANTS IN LOW AND MEDIUM WATER-STRESS AREAS	AVERAGE CAPACITY FACTOR OF PLANTS IN HIGH WATER-STRESS AREAS
By plant size	> 2000 MW	73.4%	82.4%
	1000–2000 MW	55.5%	51.8%
	500–1000 MW	43.7%	39.0%
	100–500 MW	38.2%	32.6%
	<100 MW	39.8%	38.1%
By fuel type	Biomass	45.1%	39.7%
	Coal	62.2%	50.7%
	Gas	31.2%	25.2%
	Nuclear	84.0%	88.8%
	Oil	23.2%	7.4%
	Other	31.6%	24.4%
By unit built year	Before 1970	48.7%	60.5%
	1971–80	46.0%	40.6%
	1981–90	68.5%	45.9%
	1991–2000	60.4%	47.2%
	2001–10	63.0%	51.1%
	2011–16	53.9%	45.2%

Plants with an installed capacity over 1 GW account for 69.4 percent of India's total thermal capacity. Plant size distributions are similar between high-stress and low-and medium-stress regions. A total of 65.8 percent of the thermal capacity in high water-stress regions belongs to plants with an installed capacity over 1 GW, and that number is 72.1 percent in low and medium water-stress regions.

5. Potential Revenue Losses Calculation for Power Plants

The unit-wise capacity and number of outage days are compiled from CEA's Daily Outage Reports. The function below describes the calculation for potential losses in revenue from sale of power for a single generating unit.

$$UPL = IC \times OD \times 1000 \times 24 \times \frac{RSP}{(100 \times ER)}$$

Where, UPL is the unit level potential losses in revenue from sale of power, IC is the installed capacity (MW) of the unit, OD is the number of outage days of the unit, RSP is the rate (Paise) of sale of power for the plant (or the unit when available), and ER is the exchange rate of the U.S. dollar to the Indian rupee.

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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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