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Water for electricity in India: A multi-model study of future challenges and linkages to climate change mitigation

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HIGHLIGHTS

- Water withdrawals and consumption for electricity generation in India are analyzed.
- Five modeling teams tested several scenarios for water use through 2050.
- Effects of cooling technologies and water saving policies are analyzed.

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ABSTRACT

This paper provides projections of water withdrawals and consumption for electricity generation in India through 2050. Based on the results from five energy-economic modeling teams, the paper explores the implications of economic growth, power plant cooling policies, and electricity CO_2 emissions reductions on water withdrawals and consumption. To understand how different modeling approaches derive different results for energy-water interactions, the five teams used harmonized assumptions regarding economic and population growth, the distribution of power plants by cooling technologies, and withdrawals and consumption intensities. The multi-model study provides robust results regarding the different but potentially complementary implications of cooling technology policies and efforts to reduce CO_2 emissions. The water implications of CO_2 emissions reductions depend critically on the approach to these reductions. Focusing on wind and solar power reduces consumption and withdrawals, a focus on nuclear power increases both, and a focus on hydroelectric power could increase consumptive losses through evaporation. Policies focused specifically on cooling water can have substantial and complementary impacts.

1. Introduction

India is one of the most water-stressed nations in the world. Fifty-four percent of India's total area faces high or extremely high water stress [1], and the country is close to being categorized as "water scarce" nation [2]. According to a World Resources Institute study, India's baseline water stress scored 3.6 out of 5.0 in 2010, which indicates a high ratio of total annual water withdrawals to total annual available renewable supply [3]. The country relies heavily on groundwater, and 54% of India's groundwater wells face falling water tables [1]. India is one of the countries with the world's highest rates of groundwater depletion [4].

Continued economic development will lead to increasing demands for water—for agriculture, electricity, industry, and households—putting pressure on local and national planners to develop long-term and forward-looking solutions. Climate change could substantially alter the timing, quantity, and location of run-off, including changes to monsoon patterns. Climate change mitigation will also alter the demands for water through, for

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example, changes in the electricity mix or the production of bioenergy.

India is the fifth largest electricity producer in the world, but nearly 288 million Indians still have no access to the electricity grid [5,6]. The Indian government aims to substantially increase energy access for millions of Indians and increase the use of electricity by those who already have access. The Indian government has started the *Power for All* campaign to achieve electrification of all villages in India by the end of 2019. Projections from the International Energy Agency (IEA) indicate that India could add about 600 million new electricity consumers by 2040. That electricity demand might grow by 5% per year [7].

Expanding electricity production could exacerbate potential water scarcity. Given limits to water availability, satisfying agricultural and other needs could result in the curtailment of electric power plants and associated blackouts or brownouts. Conversely, increasing water demands for electricity could have repercussions for agriculture and households. Several regions in India are increasingly relying on pumped ground water to meet municipal and agricultural needs, as is seen in some water-scarce countries where conventional water resources are inadequate to meet demands [8,9]. A failure to plan adequately for the long term could lock in approaches to water management, agriculture, and electricity that could prove limiting for decades to come.

India declared a voluntary goal of reducing the emissions intensity of its GDP by 30–35% over 2005 levels by 2030 [10]. The power sector contributes 51% of CO_2 emissions in India [11]. Policies to "decarbonize" electricity generation could help constrain future water demands, but the effect will depend on the approach to decarbonization. On April 22, 2016, India, along with 174 member countries of the United Nations, signed the Paris Agreement to reduce greenhouse gas emissions across the globe. India ratified the Paris Agreement on October 2, and the agreement entered into force on November 4, 2016. Reducing CO_2 emissions from electricity generation is critical for achieving a reduction in emission intensity. As part of that agreement, all countries will need to make major changes in the way that they produce electricity, moving from freely emitting coal and gas generation to increased use of some combination of renewable power (such as wind, solar, and hydroelectric power), nuclear power, and coal or natural gas with carbon dioxide capture and storage (CCS). These different options will have very different implications for electricity water demands. Solar photo-voltaic (PV) and wind power for example, require no water for cooling, whereas nuclear power and coal or gas with CCS are still thermal power plants with the need for cooling water. Evaporative losses from reservoirs for hydroelectric power can be substantial.

At the same time, the challenge of growing water demand for electricity production is increasingly being realized by policy makers in India, as reflected in the Government of India (GOI) rules to minimize water consumption by inland power plants. To explore the implications of growing electricity demands, efforts to reduce electricity-sector CO_2 emissions, and power plant cooling technology regulations, this study brings together four leading Indian modeling teams and one US modeling team to explore the following questions. First, how will water withdrawals and consumption from India's power-generation sector increase in the future? Second, how would decarbonization of India's power-generation sector affect water withdrawals and consumption? Third, how would a shift towards water-saving technologies impact water withdrawal and consumption in the power sector? Finally, how might these forces interact with one another? Understanding the answers to these questions is critical because Indian decision makers are considering choices in the electricity sector that will affect their country for years to come.

A number of studies have explored these issues using individual models. Most generally, there is a growing body of literature on the energy-water nexus in various countries and at various scales, for example in the US [12–23], China [24–31], Middle East and North Africa [32], Saudi Arabia [8,33], Mexico [34], and Spain [35]. Researchers have also analyzed water availability for power generation and for various climate change mitigation options at the global scale [36–43].

While water-energy issues have been analyzed for the largest economies like the US and China, there are surprisingly few studies on the water-energy nexus in India. In the context of India's power sector, the IEA estimated water use in 2010 as 40 billion cubic meters (bcm) for withdrawal and 4 bcm for consumption, with the vast majority in each category going to electricity generation [44]. Mitra, Bhattacharya, and Zhou calculated India's water demand (withdrawals) for electricity generation in 2010 as 49 bcm [45]. Bhattacharya and Mitra estimated total water demand for electricity generation at about 227 bcm in 2050, which would create a deficit of 100 bcm per year in terms of annual water supply and demand, or about a 10% gap in the total annual utilizable water [46]. However, the uncertainty of India's water use is very high. Studies show that industry accounts for 9% of water consumption in India [2], and thermal power plants account for about 88% of the total industrial water demand in the country [47,48].

While previous studies have provided valuable contributions to the understanding of the energy-water nexus in India, the fact that they were produced by different modeling teams using different assumptions makes comparison difficult and also limits assessment of how robust the results might be.

This study builds on that previous work by using multiple models with coordinated assumptions. Multi-model studies such as this provide a means to identify areas of agreement and robust understanding as well as areas in which substantial uncertainty remains. The unique contribution of this study is that this is the first time that four Indian modeling teams and one US-based team have come together for an India-specific assessment. This assessment and the results will provide policy makers and other stakeholders with a more robust assessment of India's future needs for water for thermal power plants.

This study analyzes water withdrawals and water consumption by India's electricity-generating power plants. Following the same definitions given in the literature [49,50], "water withdrawal" is "water removed from the ground or diverted from a surface-water source," and "water consumption" is "the portion of withdrawn water not returned to the immediate water environment."

The remainder of this paper proceeds as follows. Section 2 provides a brief overview of water use for electricity in India today. Section 3 explains the methods used in the paper, including the models, the scenarios, and the common assumptions. Results are provided in Section 4, and Section 5 provides final thoughts.

2. Electricity water use in India today

The estimates of water use in India's statistics are not based on measurements of actual use but on specific assumptions for each sector [51], and there is no comprehensive database to gauge reliance of the power sector on fresh water resources. The Center for Study of Science, Technology and Policy (CSTEP) estimated that in 2010, the majority of the plants (about 84% of coal-based thermal power plants by count) in India used fresh water resources. Plant-level data from the Central Electricity Authority database for existing plants was cross-referenced with data collected on water sources. These included 48% authenticated data points [52], 36% non-authenticated sources (newspaper articles, industry

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