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The vulnerability of thermoelectric power generation to water scarcity in China: Current status and future scenarios for power planning and climate change

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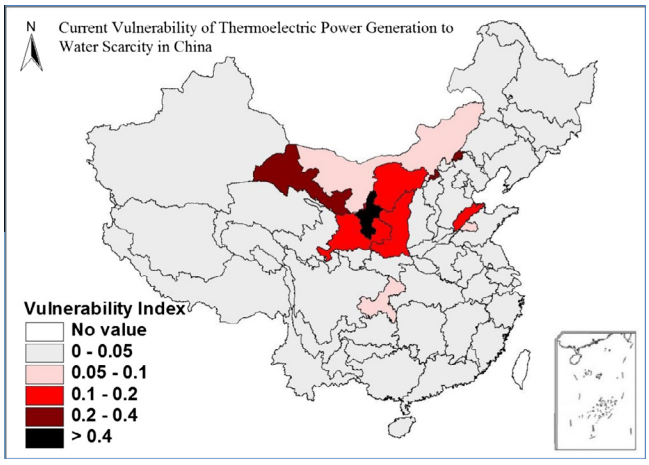
HIGHLIGHTS

- We assess the severity and location of water and electricity conflicts in China.
- An index was constructed to measure the vulnerability of thermoelectric plants.
- Power generation in seven regions is highlighted as vulnerable to water shortage.
- Decreasing water withdrawal intensity alone cannot solve the vulnerability concerns.
- Regions where climate change will aggravate the vulnerability are highlighted.

GRAPHICAL ABSTRACT



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ABSTRACT

Although China has experienced a wide variety of regional conflicts between water scarcity and electricity generation, there are few comprehensive quantifications that explicitly reveal the location and severity of these conflicts. Triggered by the soaring need for such information, we performed a high-resolution evaluation and projection of the spatial vulnerability of thermoelectric power generation to water scarcity problems. The study provides a comprehensive assessment by incorporating thermoelectric plants' reliance on water, local water supply stress and future impacts brought about by planning and climate change into the analysis simultaneously. To measure the vulnerability of thermoelectric plants to water scarcity, a vulnerability index was constructed and multi-disciplinary approaches were integrated to quantify this index. Seven hotpots in North China were highlighted as power-vulnerable to water scarcity currently. In order to fulfill the power generation target in the future, less-vulnerable watersheds identified by this study are suggested to become the sites of future power plants. Besides, lowering the water withdrawal intensity of power plants alone is not enough to solve the vulnerability concerns. Instead, it is necessary to implement other water management, including water rights allocation in the transboundary river basins. This paper also highlights regions where climate change will threaten power

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generation by decreasing the water availability. These insights are valuable for adding the alleviation of water and electricity conflicts to climate change adaptation agenda.

1. Introduction

Water and energy security are becoming two of the great critical challenges in China and the world due to the huge gap between the growing demand and the limited supply of both [1]. The tight linkage between water and electricity generation [2,3], makes these two issues closely intertwined. First, electricity generation is constrained by water shortage, since a substantial volume of water is required for cooling, generating steam, generating hydropower and more [4]. Water scarcity can lead to a massive reduction of power generation [5] and an increased vulnerability of the power system [6]. This will likely have major economic consequences, particularly in terms of rising electricity prices [7]. Furthermore, a significant amount of water allocation to the power sector may increase water supply stress and exacerbate the competition among various water users [6].

To understand the relationship between water and electricity, existing studies have quantified and projected water demand of power generation [8–10]. Some studies have demonstrated water and electricity conflicts by comparing the large volume of water demand for power plants and the limited water supply [9,10]. In China, Zhang and Anadon [9] investigated the current life-cycle water intensity of the energy sector, and found that the arid north and northwest regions have more energy-related water consumption. Cai et al. [10] projected provincial water withdrawal in the energy sector by 2030, and illustrated the geographic mismatch of water resources and energy production. Another area that has attracted significant attention is the impact of climate change on power generation when water temperature and availability is altered [11,12].

The aforementioned work has contributed profoundly to an increased understanding of water and electricity conflicts. However, there are few specific, comprehensive, and quantifiable studies that demonstrate the exact location and severity of current and future water and electricity conflicts. A study by Sovacool and Sovacool [13] highlighted the most likely locations of severe water shortages brought about by thermoelectric capacity additions in the U.S. by separately ranking each region according to population growth, thermoelectric capacity additions and increasing summer water deficits. However, this study focused only on the negative drivers (which have the potential to aggravate the water and electricity conflicts) while ignoring the positive impacts (which can offset the aggravation or even eliminate the conflicts). Moreover, the ranking method used in this study fails to project the location and severity of conflict explicitly if both negative and positive impacts are taken into consideration. The quantitative assessment of the water and electricity conflicts are available in another two studies [14,15], which has identified the power plant locations that drive water-supply stress by calculating the Water Supply Stress Index both with and without power plant water use in U.S. and China. These two studies [14,15] addressed one side of the water–electricity conflicts, which is the water stress caused by power generation. However, they didn't identify the other side of the conflicts, which is the vulnerability of power generation to water scarcity. Besides, they did not incorporate the impact of power planning, water management or climate change into the quantifications. Hence, it has remained challenging for policy makers to fully understand the character and evolution of water and electricity conflicts.

In order to fill the knowledge gap on the issue of location and severity, this study provided high-resolution quantifications of the water and electricity conflicts. In this study we analyze China, where there have been spatially uneven water and electricity conflicts [16,17]. Water and electricity conflicts in China are often addressed as the high vulnerability of thermoelectric generation to water scarcity or the various conflicts of hydropower generation and other water uses. In this study, we focus on the former, and leave the latter to other studies. Based on a framework of water, electricity and climate change nexus (shown in Fig. 1), this study provides a comprehensive assessment of thermoelectric plants' vulnerability to water scarcity. The assessment takes into consideration thermoelectric plants' reliance on water, local water supply stress and future impacts brought by planning and climate change. And to capture these factors quantitatively, a vulnerability index was constructed referencing the River Basin Vulnerability Index approach [18,19] and other vulnerability measurements [20–22]. Besides, multi-disciplinary approaches were adopted to calculate the index. Beyond current status and future projections, this study

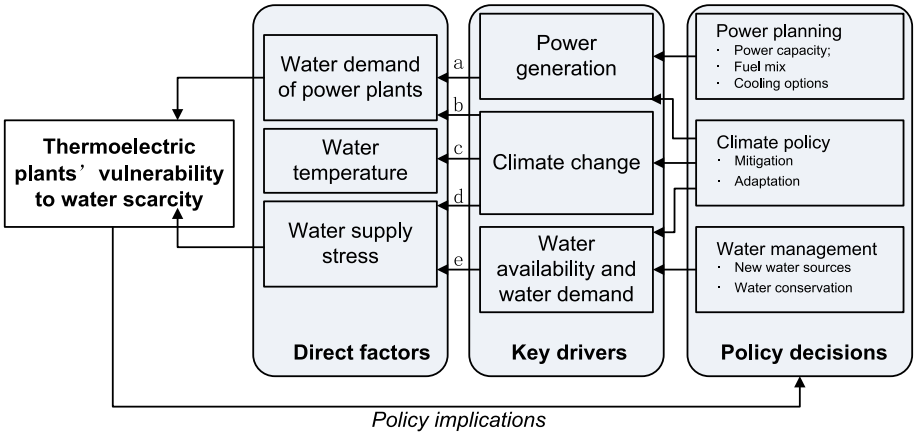

Fig. 1. The relationships among water, electricity and climate change which are related to thermoelectric plants' vulnerability to water scarcity. Some relevant existing studies are provided as references: (a) Refs. [8–10]; (b) Refs. [11,12]; (c) Ref. [44]; (d) Refs. [35,36,45,46]; (e) Refs. [39,40,47,48].