Applied Energy xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Water conservation from power generation in China: A provincial level scenario towards 2030

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HIGHLIGHTS

- Disaggregate water consumption by electric power generation in 2015–2030 is estimated.
- Renewable energy development and technology advancement can jointly reduce over 60% of water consumption.
- Water consumptions by natural gas and nuclear power gradually emerge.
- Discrepancy in geographical distributions between water consumption and water resource continue existing.
- Contribution of scale, structure and technology effects to water saving are assessed using decomposition approach.

ARTICLE INFO

Keywords:
Electric power generation
Water consumption
Renewable power
Cooling technology
Decomposition analysis

ABSTRACT

Electric power generation poses a high stress to the water supply in China. In this study, we quantified China's water consumption by electricity generation from 2015 to 2030 by considering different scenarios of electric power generation structure and water consumption intensity, and analyzed water consumption by different sources of electric power and its regional disparity. We found there is a significant difference in water consumption among the presented six scenarios with water consumption varying from 1.78 to 3.62 gigatonnes (Gt) in the year 2030. We also found that water consumption by coal-fired power decreases while water consumption by natural gas and nuclear power increases. Water consumption was and will still be concentrated in the three northern and coastal areas of China. However, the development of renewable power and adoption of water saving technology would contribute to water consumption reduction in these regions. We used a decomposition model for investigating the scale, structure and technology effects of electric power generation on water consumption, and found they present positive, negative and negative effects, respectively. The strongest factor in reducing water consumption is the technology effect, highlighting the importance of adopting water conserving cooling technology. Our findings yield important hints for China's water conserving policy making in renewable power development, cooling technology choices and siting decisions.

1. Introduction

China's air pollution and greenhouse gas emissions attributed to fossil energy consumption have attracted wide concern. The electric power sector has the largest coal consumption and CO_2 emissions in China and is responsible for China's severe air emissions attributable to energy consumption [1–5]. In addition to air pollution concerns, water consumption issues brought about by electric power development have attracted more and more attentions.

The water scarcity problem gradually emerges along with the increasing water consumption.[1] The power sector, as the second largest water consumer following the agricultural industry, accounts for 15%

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[1] There are two distinct kinds of water use: water withdrawal and water consumption. Water withdrawal is the water withdrawn from a water source, which includes the part that will be returned to a water source once more; while water consumption is the water consumed and not available anymore because of reasons like evaporation or transpiration during its usage process. Because future water withdrawal is subject to dramatic uncertainties of water reuses of power generation, and also a portion of this kind of water use can be returned to the water source for re-usage, it is hard to evaluate water stress by analyzing water withdrawal. Therefore, we focus on estimating water consumption by electric power sector in this study.

http://dx.doi.org/10.1016/j.apenergy.2017.09.096
Received 16 May 2017; Received in revised form 12 September 2017; Accepted 16 September 2017

of total water consumption in the world; and 90% of electric power generation relies on water consumption. In China, water consumption by power generation accounts for a significant fraction of total water consumption. According to National Bureau of Statistics of China [6], water consumption by power generation was 18.21 gigatonnes (Gt) in 2012, accounting for 39% of total industrial water consumption. It is projected that by 2026 electric power generation will be double from the 2012 level [7]. The dramatic increase in consumption of electricity is said to stress the water supply in the future.

Although the impact of electric power generation on water resource is evident, three main factors still need to be addressed. First, the structure of power generation by 2030. In order to control coal use and reach peak CO_2 emissions, the Chinese government has set goals of increasing the share of non-fossil energy to 20 percent in the total primary energy consumption by 2030 [8]. A lot of research has focused on the contribution of non-fossil energy development to lowering coal consumption and alleviating air pollution in China [5,9–15]. However, little research has investigated the impact of non-fossil energy development on water consumption. Therefore, further research is still needed to show how non-fossil energy development affects water consumption in China.

The second factor is the cooling technology choice of power generation by 2030. The electric power sector mainly uses water for cooling purposes, and water consumption can be dramatically different among different types of cooling systems. In general, dry cooling and hybrid cooling systems consume less water than conventional methods like steam tower cooling systems because dry cooling systems use air and hybrid cooling systems use a combination of air and water as main sources for cooling [16–18]. Using natural gas power as an example, water consumption by dry cooling technology is generally less than one percent by steam tower technology, and the adoption of dry cooling technology may have significant water conservation effects. Therefore, the possible choice of cooling system will have a great impact on water consumption by electric power generation.

The third factor is the geographical layout of power generation and its corresponding regional disparity of water consumption. Geographically unbalanced water scarcity in China is largely attributed to the mismatch of water resource and water consumption. China's water resource is concentrated in South and Southwest while the North is generally under water stress or water scarcity [19]. However, China's thermal power plants are centralized in these water deficit areas. The struggles between satisfying electricity supply and water supply are especially prominent in North China during some seasons (China Water Risk and International Renewable Energy Agency 2016). The study of current and future geographical distribution of power generation and its corresponding water consumption will yield important considerations in policy making for properly situated generators.

There is some literature investigating the relationship between energy development and water consumption in China. Some studies looked at the energy-water-food or energy-water nexus in China [19–21]. These studies provided insightful understandings and presented recommendations to face the main challenges associated with water conservation and energy development. For example, Tan et al. [19] offered an overview of China's water resources and stress, discussed the challenges of water supply in ensuring both energy and food security. Some studies also quantitatively analyzed energy-water nexus in China from different angles [22–26]. For example, Gu et al. [22] estimated the effects of water conservation by implementing energy-saving policies. Duan and Chen [23] estimated embodied water consumption in international energy trade. Qin et al. [24] analyzed both water withdrawal and water consumption for China's energy supply in 2010, and projected different scenarios of water withdrawal and water consumption by this sector in 2034. Zhou et al. [26] investigated the impacts of an energy tax on both energy and water resources.

Some other studies looked at water consumption by electricity generation and transmission in China [27,28]. For example, Feng et al. [27] investigated water consumption by electricity generation between 2000 and 2010 from a life cycle perspective. Part research also focused on embodied water consumptions in electricity transmission, to evaluate the impact of China's interprovincial electricity transmission on water stress [29–31]. Other researchers focused on projecting water consumption by thermal power in future. Sovacool and Sovacool [32] depicted geographical dispatch of new thermal power from 2000 to 2025, and analyzed water stress by thermal power generation in 2025; Liao et al. [33] projected water consumption by thermal power to 2050 and its spatial and temporal characteristics; Zheng et al. [34] projected water withdrawals by thermal power from 2011 to 2030. Although these studies investigated future water consumption by thermal power, they did not explicitly consider the effects of renewable power penetration like wind, solar PV, and biomass, and therefore, could not reflect the contribution of power structure upgrade on water conservation.

Some also explored the nexus between water consumption and CO_2 emissions from power generation [35–39]. Li et al. [35] focused on wind power and analyzed water savings and CO_2 reductions from wind power development, CWR and IRENA [38] analyzed the intensity changes of CO_2 emissions (g/kW h) and water consumption (m^3/MW h) for China's power sector from 2013 to 2030; WRI [37] also analyzed intensities of CO_2 emissions (kg/MW h) and water consumption (m^3/MW h) of different cooling systems during their lifetime span, but these two studies did not quantify total amount of water consumption and hence cannot reflect water stress by the generation of electricity, Huang et al. [39] assessed water withdrawal and CO_2 emissions by power generation in China by 2050 based on different scenarios of carbon and water constraints, but it did not specify where water will be consumed.

Previous studies have argued the challenges by energy-water nexus and estimated the water consumption by thermoelectric power development, but few of them have depicted explicitly where the water would be consumed considering provincial differences in cooling technology, and how future renewable energy penetration would affect water consumption at the provincial level. To address these knowledge gaps, this paper focuses on the estimates of water consumption by electric power generation under different scenarios from 2015 to 2030, considering possible futures of power generation structure, water consumption intensity, and geographical layout. For this purpose, this paper develops a bottom-up approach that incorporates a water consumption module and a dispatch model of the power sector at the provincial level in China.

The remainder of this paper is organized as follows. In the next section, we introduce the methods and data used for the estimation of China's water consumption by electric power generation. In Section 3 we present the results of China's water consumption by power generation. In Section 4 we discuss the results and Section 5 presents our conclusions.

2. Methods and data

2.1. Methods

We developed an integrated approach to project China's water consumption by electric power generation and investigated its determinants. As shown in Fig. 1, the approach is composed of a power sector dispatch model from China National Renewable Energy Centre that provides power generation from each source in each province, a water consumption projection module that uses the best available water consumption intensity data, and a decomposition analytical approach to explore the factors influencing water consumption by electric power generation.

2.1.1. Economic dispatch optimization (EDO) model

The EDO model is an economic dispatch optimization, unit commitment, and capacity expansion linear programming model. This model, subjects to a given scenario's boundary conditions, determines