Drivers of water use in China’s electric power sector from 2000 to 2015

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Abstract
This study, for the first time, investigates the historical changes of the water use in China’s electric power sector on a regional level and quantifies the impacts of four factors that have influenced the remarkable changes: population, power production per capita, power plants’ type and their cooling technology choice. From 2000 to 2015, water withdrawal and consumption in China’s electric power sector, excluding hydropower, have increased from 40.75 and 1.25 billion m³, respectively, to 124.06 and 4.86 billion m³. As population growth in China has stabilized, population no longer provides an upward pressure on power production and the corresponding water use. On the contrary, power production per capita has played the most significant role contributing to 103.40 and 3.84 billion m³ of water withdrawal and consumption increases respectively, though the effect is no leveled off. The electric power sector’s water use would have been much greater had it not been for changes in plant type and cooling water technology. Energy transformation to low-carbon sources has mitigated water withdrawals and consumption by 14.46 and 0.43 billion m³ respectively during the study period. This beneficial reduction in water use is a co-benefit of a series of policies primarily aimed to reduce carbon emissions and other air pollutants. Changing cooling technologies has offset 14.07 and 0.10 billion m³ of water withdrawal and consumption increases nationally, but the effects varied by region.

1. Introduction
In the past few decades, the rapid economic growth of China has been accompanied by markedly increased electric power (hereinafter used interchangeably with ‘power’) production, resulting from extensive industrialization, urbanization and growing population. Starting from the 21st century, China’s power production has more than quadrupled from 1328 billion KWh in 2000–5810 billion KWh in 2015 and has overtaken the US as the biggest power producer in the world (National Bureau of Statistics of China 2016). This expansion has notable externalities, for air quality, greenhouse gas emissions and water usage. Due to several recent water-induced power curtailments around the world (McCall et al 2016, Gjorgiev and Sansavini 2018), water use for electricity production, the so-called ‘water-for-electricity’ nexus, as well as potential corresponding conflicts and trade-offs have raised growing concerns.

Besides hydropower, a large amount of water is used at thermoelectric power facilities for cooling purposes (Vassolo and Doll 2005, Stillwell et al 2011, Byers et al 2014, Grubert and Webber 2015, Sanders 2015, Stillwell et al 2017). Consequently, global power productions may be exposed to water-related risks, especially under a changing climate (van Vliet et al 2012, Byers et al 2016, van Vliet et al 2016).

China is particularly prone to potential water-electricity conflicts due to its unevenly distributed water endowments (Zhang and Anadon 2013) and the prevalence of thermoelectric power plants on inland waterways (Liao et al 2016). Moreover, potential changes in water availability and variability, both geographically and seasonally, induced by future climate change may further expose some Chinese regions, e.g.
northern China, to intensified water risks in the power sector (Sadoff et al 2015, Zheng et al 2017).

A growing amount of scholarly work has paid attention to China’s water-for-electricity nexus. Some studies have quantified the current water use in China’s power sector (Liao et al 2016, Zhang et al 2016, Zhang et al 2017) and identified areas that are vulnerable to water risks for power generation, e.g. Jing-Jin-Ji megalopolises (Zheng et al 2017), whilst others have addressed the future possibility of China’s power sector competing with water users in other sectors (Cai et al 2014, Li et al 2017) and potential conflicts due to uncoordinated policies (Qin et al 2015, Liao et al 2016). Yu et al (2011) concluded that facilitating and adopting water-saving technologies is the key to avoiding such conflicts. However, in order to better understand such complexity and to inform future policy formulations, it is of great importance to look back into the past trajectories of China’s water-for-electricity nexus and to identify the impacts of the factors driving its historical changes.

According to the Impact = Population × Affluence × Technology (IPAT) model (Ehrlich and Holdren 1971, Mi et al 2017), we attribute China’s historical water-for-electricity change to three corresponding factors: (1) population, (2) power production per capita (MWh/p) and (3) water intensities, measured as water use per unit of electricity generated (m³/MWh). Water use includes both water withdrawal and consumption. Water withdrawal is the total amount of water abstracted from the natural environment, and the share of water that is not returned to any water body after the production processes is defined as water consumption (AQUASTAT 1998). Individual power plant’s water intensities vary primarily by its generation technology and cooling technology (Macknick et al 2012). Prevalent generation technologies include coal, solar PV, wind, hydro and so on. This study does not consider hydropower because the quantification of its water use embodies many methodological disputes and uncertainties, especially regarding the attribution of water use in multi-purpose reservoirs (Bakken et al 2016). In terms of cooling technologies in thermoelectric power plants, air cooling systems, which use air to cool down the steam exiting turbines, use the least water. Closed-loop cooling systems, where cooling water is recirculated, have much higher consumptive water use but significantly lower water withdrawal than open-loop cooling systems that use running water. Power plants’ water intensities are also affected by other technological factors, for example, boiler technology. However, compared with plant type and cooling technologies, their effects are much smaller by an order of magnitude for water consumption and three orders of magnitude for water withdrawal (Macknick et al 2012). Therefore we only consider plant type and cooling technology in this study.

Considering the significant regional variations highlighted by previous studies (Cai et al 2014, Liao et al 2016, Zhang et al 2016), this study is conducted on China’s six regional power grids: Northeast, Northwest, North, East, South and Central Grids. Inter-regional power transmissions only occupied a small proportion of energy demand (5% in 2014, Chinese Electricity Council 2015a), so we do not account for these transfers in our regional allocation of water use.

2. Method and data

2.1. Methods

Until 2015, China’s non-hydro electricity was almost entirely produced from fossil fuels (coal and gas), nuclear, wind and solar PV (China Electric Power Statistic Yearbook Editorial Board 2015). We focus on the water use of fossil fuel thermoelectric power plants (hereinafter used interchangeably with ‘thermoelectric power’) in this study for two reasons: (1) all China’s existing nuclear power plants are located along the coast and utilize sea water for cooling purposes; (2) solar PV and wind power use negligible amount of water (Macknick et al 2012). Furthermore, gas-fired power generation only reached 3.9% in 2015 (China Electricity Council 2015b) and data are limited to a regional level, so we use the same cooling water usage factors for gas as for coal.

Therefore, water use in the power sector can be quantified according to equation (1) below:

\[
W_i = E_i \cdot P_i \cdot S_{thermal,i} \cdot I_i,
\]

where \(W_i\) is the total water use; \(E\) denotes the electric power production per capita in the six regional grids; \(P\) and \(S_{thermal}\) represent population and the share of thermal power production, respectively; \(I\) is thermoelectric power production’s water intensities for either withdrawal or consumption, which are approximated by those of coal-fired power plants; \(i\) represents the region.

According to equation (1), changes in the power sector’s water use can be attributed to four underlying determinants: electric power production per capita \(E\), population \(P\), the share of thermoelectric power production \(S_{thermal}\) and water intensity \(I\). In order to assess the influences of various social, economic and technological factors on environmental issues, index decomposition analysis has been widely employed (Hoekstra and van der Bergh 2003). We adopt the additive mathematical form as its results are easier to interpret and thus more commonly used in the existing literature (Su and Ang 2012). Accordingly, the power sector’s water use change, \(\Delta W_i\), can be expressed as equation (2):

\[
\Delta W_i = E_i^e + P_i^e + S_{thermal,i}^e + I_i^e,
\]

where \(E_i^e, P_i^e, S_{thermal,i}^e\) and \(I_i^e\) represent the impacts brought by changes in each factor \(E, P, S_{thermal}\) and \(I\).
respectively. During the time interval \([0, t]\), \(\Delta W_i\) can also be expressed as equation (3):

\[
\Delta W_i = W_i^0 - W_i = E_i^0 \cdot P_i^0 \cdot S_{\text{thermal},i}^0 \cdot I_i^0 - E_i^0 \\
\cdot P_i^0 - S_{\text{thermal},i}^0 \cdot I_i^0 = (E_i^0 + \Delta E_i) \cdot (P_i^0 + \Delta P_i) \cdot (S_{\text{thermal},i}^0 + \Delta S_{\text{thermal},i}) \\
\cdot (I_i^0 + \Delta I_i) - E_i^0 \cdot P_i^0 \cdot S_{\text{thermal},i}^0 \cdot I_i^0.
\]

(3)

In early studies, the effect of each changed factor in equation (2) was quantified by keeping the other factors the same as either in the starting year (Laspeyres method) or in the ending year (Paasche method), or the mean values (Marshall–Edgeworth method). Take \(E_i^0\) for example, \(E_i^0\) was estimated as \(\Delta E_i \cdot \Delta P_i \cdot S_{\text{thermal},i}^0 \cdot I_i^0\), \(\Delta E_i \cdot P_i^0 \cdot S_{\text{thermal},i}^0 \cdot I_i^0\) or \(\Delta E_i \cdot 1/2 \cdot (P_i^0 + S_{\text{thermal},i}^0) \cdot (I_i^0 + P_i^0 \cdot S_{\text{thermal},i}^0 \cdot I_i^0)\). However, these decomposition methods created residual terms from equation (3), namely, all terms including changes from more than one factor, for example \(\Delta E_i \cdot \Delta P_i \cdot S_{\text{thermal},i}^0 \cdot I_i^0\).

Following the ‘jointly created and equally distributed’ principle in Sun (1996, 1998) developed the S/S method for attributing effects jointly created by two or more factors, e.g. \(\Delta E_i \cdot \Delta P_i \cdot S_{\text{thermal},i}^0 \cdot I_i^0\), equally among the changed factors, i.e. \(\Delta E_i\) and \(\Delta P_i\). In this way, the residual errors are avoided. The S/S method is thus called complete decomposition and is employed in this study. Accordingly, each term in equation (2) can be derived by breaking down equation (3) mathematically. Taking \(E_i^0\) for example, it can be estimated by equation (4) below:

\[
E_i^c = \Delta E_i \cdot P_i^0 \cdot S_{\text{thermal},i}^0 \cdot I_i^0 + \frac{1}{2} \cdot \Delta E_i \cdot (\Delta P_i \cdot S_{\text{thermal},i}^0 \cdot I_i^0 + P_i^0 \cdot \Delta S_{\text{thermal},i}^0 \cdot I_i^0 + P_i^0) + \frac{1}{2} \cdot \Delta E_i \cdot (\Delta P_i \cdot \Delta S_{\text{thermal},i}^0 \cdot I_i^0 + \Delta P_i \cdot S_{\text{thermal},i}^0) \\
\cdot \Delta I_i + P_i^0 \cdot \Delta S_{\text{thermal},i}^0 \cdot \Delta I_i + \frac{1}{4} \cdot \Delta E_i \cdot \Delta P_i \\
\cdot \Delta S_{\text{thermal},i} \cdot \Delta I_i.
\]

(4)

Similarly, \(P_i^0\), \(S_{\text{thermal},i}^0\) and \(I_i^0\) can be attributed (more detailed description of the method can be found in the supplementary information available online at stacks.iop.org/ERL/13/094010/mmedia).

However, as interactions between different factors are unknown, such assumption generates uncertainties. In order to demonstrate such uncertainties, we calculate the effect of each driving factor under two additional scenarios: (i) without considering joint terms; and (ii) fully accounting unweighted joint terms. Taking \(E_i^0\) as an example, the range of uncertainties \([E_i^c, E_i^c]\) can be calculated as in equations (5) and (6)

\[
E_i^c = \Delta E_i \cdot P_i^0 \cdot S_{\text{thermal},i}^0 \cdot I_i^0,
\]

\[
E_i^c = \Delta E_i \cdot P_i^0 \cdot S_{\text{thermal},i}^0 \cdot I_i^0 + \Delta E_i \\
\cdot (\Delta P_i \cdot S_{\text{thermal},i}^0 \cdot I_i^0 + P_i^0 \cdot \Delta S_{\text{thermal},i}^0 \cdot I_i^0 + P_i^0 \\
+ \Delta P_i \cdot S_{\text{thermal},i}^0 \cdot \Delta I_i + \Delta E_i \cdot (\Delta P_i \cdot \Delta S_{\text{thermal},i}^0 \cdot I_i^0 \\
+ \Delta I_i + P_i^0 \cdot \Delta S_{\text{thermal},i}^0 \cdot \Delta I_i) + \Delta P_i \cdot \Delta S_{\text{thermal},i}^0 \cdot \Delta I_i). + \Delta E_i \cdot \Delta P_i \\
\cdot \Delta S_{\text{thermal},i} \cdot \Delta I_i.
\]

(6)

2.2. Data sources and treatment

China’s historical provincial electricity generation, thermal power production and population data were obtained from the National Bureau of Statistics of China (2016) and aggregated to the regional level. A comprehensive dataset of China’s coal-fired electricity generation units (EGUs) is compiled from Carbon Monitoring for Action (Center for Global Development 2015), World Electric Power Plants Data Base (Utility Data Institute, Platts Energy InfoStore 2015), Global Coal Plant Tracker (CoalSwarm 2017) and Enipedia (Davis et al. 2015), which includes all coal-fired units’ capacities, commissioned years and boiler technologies. Cooling technologies employed by individual power plants are identified via Google Earth satellite imagery in a similar way to the US Geological Survey (Deihl et al. 2013) following two main rules: (i) closed-loop cooling towers can be visually identified; (ii) power plants without such cooling towers but located close to water bodies, primarily in the southern regions, and with discharge outlets are equipped with open-loop cooling systems, otherwise with air-cooling ones. Data acquired from the steps above are then crosschecked with existing information on power plants’ cooling technologies in the above-mentioned datasets as well as individual power plant’s websites. Over 2300 coal-fired EGUs are included whose aggregate capacity amounts to 870 GW, which equals to about 96.7% of the nation’s total in 2015. Although water withdrawal intensities are not available in China, China’s technology is on par with that in the US (Zhang et al. 2016), so water withdrawal and consumption intensities of EGUs of a certain cooling type are approximated by those compiled by Macknick et al. (2012) for the US. Regional water withdrawal and consumption are calculated assuming that all coal-fired power plants in a same province have the same running hours each year. This assumption is reasonable because China’s generator dispatch mechanism seeks to assure all contracted power generators comparable running hours (The Regulatory Assistance Project 2016). The historical changes of the four driving factors can be found in the supplementary information.
3. Results and discussion

3.1. Historical trajectories of water uses in China’s electric power sector

As shown in figure 1, from 2000 to 2015, the national total water consumption and withdrawal for power production in China grew from 1.25 and 40.75 billion m$^3$ to 4.86 and 124.06 billion m$^3$, respectively. Water withdrawal peaked in 2013 at 129.82 billion m$^3$, which is because power productions in regions with large water withdrawal intensities, i.e. south, east and central, peaked in that year. In 2013, southern China suffered from record-high heat waves that could have contributed to these regions’ electricity demand peaking (USA Today 2013). Open-loop cooling systems are prevalently utilized in these above-mentioned regions where water is abundant (Liao et al 2016). As a result, the largest amount of water was withdrawn in the east, from 18.28 billion m$^3$ in 2000 to 65.01 billion m$^3$ in 2015 and peaking at 68.16 billion m$^3$ in 2013, which is followed by the south. While in the northern regions (north, northeast and northwest), particularly northwest, the amount of water withdrawn for power production was substantially smaller.

Regarding water consumption, the largest amount of water was consistently consumed in the north, from 434.13 million m$^3$ in 2000 to 1.39 billion m$^3$ in 2015, aggravating the region’s continuous severe water scarcity. When population is taken into account, the power sector’s water withdrawal per capita, 6.00 m$^3$ p$^{-1}$, while the lowest water withdrawal per capita, 7.22 m$^3$ p$^{-1}$. In comparison, the power sector’s water withdrawal per capita in the east is the highest, amounting to 250.87 m$^3$ per person.

3.2. Drivers of historical changes in China’s electric power sector’s water use

3.2.1. Effects of population and power production per capita

It can be seen from figure 2 that the increases of population and power production per capita both have had positive effects on the power sector’s water use increases. In total, from 2000 to 2015, population increase contributed to 8.43 billion m$^3$ and 295.99 million m$^3$ of water withdrawal and consumption increases, respectively, compared with 103.40 and 3.84 billion m$^3$ triggered by the rise of power production per capita. Population played the least important role, which is not surprising considering China’s population has stabilized during this period at an average annual growth rate of 0.56%, while power production per capita has kept an annual growth rate of around 10% during the same period. In the east, population growth had made a visible contribution to the water withdrawal increases, at 1.1, 2.0 and 1.5 billion m$^3$ during the three consecutive five-year periods respectively. Whereas the population effect on water consumption was the highest in the north. The north and the east are homes to China’s two rapidly expanding urban agglomerations, Jing-Jin-Ji and the Yangtze Delta region respectively. Both regions have attracted significant numbers of inward migrations for better jobs and opportunities (Wang et al 2017), which has resulted in heightened pressure on its local resources.

Growth in power production per capita played the dominant role in every region. Particularly, it had substantial effects in central, south and east China contributing to their water withdrawal increases of 15.09, 22.07 and 48.96 billion m$^3$ respectively from 2000 to 2015. Such significant effects can be explained by the large base values of water withdrawal intensities in those regions as they are relatively abundant in water resources and therefore open-loop cooling systems are commonly adopted. Regarding water consumption, the effects are relatively similar across different regions. In each region, about 100 to 300 million m$^3$ of water consumption growth was triggered by power production per capita increase every five years.

3.2.2. Effects of energy transformation

According to figure 2, energy transition—the change of the power sector’s energy portfolio—has mitigated 14.46 billion m$^3$ of water withdrawal increase and 429.30 million m$^3$ of water consumption increase in the power sector during the study period. The effect
was especially significant from 2010 to 2015, contributing to 83.67% and 80.00% of the total, respectively. During this period, transforming the energy structure offset 6.56 and 3.06 billion m$^3$ of water withdrawal increase in south and east China, respectively.

As the world’s biggest CO2 emitter, China pledged to increase the share of its non-fossil fuel to around 15% by 2020 at Copenhagen in 2009. It first proposed to diversify the energy portfolio in its 10th Five-Year Plan (2001–2005) (National People’s Congress of China 2001) and the 12th Five-Year Plan (2011–2015) (National People’s Congress of China 2011) made more specific targets aiming to decrease the share of coal in the country’s energy structure to 63%.

While China’s hydropower has occupied a relatively stable proportion of the total power production (at just below 20%), it can be seen from figure 3 that, besides hydropower, during the study period (2000–2015), even though the sheer amount of electricity produced from fossil fuel has increased drastically from 1088.48 to 4241.93 TWh, the percentage it occupies has gone down from 98.5% to just over 91.4%, which was gradually taken over by nuclear, wind power and solar PV.

The power sector is the major source of air pollution and greenhouse gas emissions in China due to its intensive coal combustion. Facing pressing local health penalties and global climate change pressures, China has taken actions to reduce its power sector’s reliance on coal, by either transforming its energy portfolio or improving coal-burning efficiencies. Sanders (2015) has conducted a meta-analysis of existing publications in the water-electricity field and identified five main aspects of the power sector that have impacts on its water uses: (1) fuel consumption structure; (2) cooling technology deployment; (3) relevant
(4) changing climate and (5) power grid characteristics. Therefore, apart from policies that directly regulate the sector’s water uses, those targeting at any one of the five domains may deliver corresponding co-benefits. For example, Webster et al (2013) found that a restriction on CO₂ emissions in the energy sector would also reduce water withdrawals by the power sector in Texas; Bartos and Chester (2014) have shown that Arizona’s Energy Efficiency Mandate and Renewable Portfolio Standard have resulted in considerable water savings.

It needs noting that some technologies that can curb the power sector’s carbon emissions may lead to increased water uses. For example, carbon capture and storage (CCS) offers the opportunity to minimize carbon emissions from fossil fuel power plants. However, as carbon capture is an energy intensive process, the parasitic loads of CCS power plants could result in larger water uses (Zhai et al 2011, Byers et al 2016). Although concentrated solar power and inland nuclear power are both feasible alternatives to reduce carbon emissions of China’s electric power sector, their on-site water uses are substantial, whereas biofuels require the largest amount of water inputs throughout the life cycle, mainly for crop cultivation (Meldrum et al 2013). On the contrary, thermoelectric power plants equipped with air cooling systems that are used to minimize their water uses emit more carbon due to lower thermal efficiencies and thus increased coal use (European Commission Joint Research Centre 2001).

3.2.3. Effects of cooling technology change
The effects of water intensity changes as in figure 2 are primarily determined by the plant fleets’ cooling technology configuration changes as demonstrated in figure 4. In total, changing cooling technologies mitigated 14.07 billion m³ of water withdrawal increase and 101.34 million m³ of water consumption increase, which varied among regions. For instance, cooling technology change contributed to 93.94 million of water consumption increase but 5.10 billion m³ of water withdrawal decrease in central China. While in northwest China, the percentage of closed-loop cooling systems has gone down from 86.6% in 2000 to 52.7% in 2015 being replaced by air cooling ones, which resulted in 169.97 million m³ of water consumption reductions. In the southern regions (central, south and east), closed-loop cooling systems are gradually replacing open-loop ones to reduce the power sector’s water withdrawals thus dependence on water supplies, but at the cost of water consumption increase. While in the northern regions (north, northwest and northeast), in response to severe local water stresses, air cooling systems have been gradually adopted to cut both water withdrawal and consumption.

The above-mentioned changes in the cooling technology configurations in China’s different regions resulted from various policies in the power sector directly and specifically targeting its water usage. At a national level, in 2012, a new national water withdrawal standard (GB/T 18916.1-2012) replaced ‘GB/T 18916.1-2002’ and set more stringent requirements regarding water uses by coal power plants with closed-loop cooling systems (General Administration of Quality Supervision, Inspection and Quarantine of China 2002, 2012). Moreover, in water scarce areas, new plants are not allowed to extract groundwater and required to employ large air-cooling units with water withdrawal intensities less than 0.18 m³ s⁻¹ GW⁻¹ (National Development and Reform Commission 2004). As a result, new power plants equipped with air cooling systems need much less time to acquire environmental permits and thus have proliferated during the last decade. Nationally, the percentage of air cooling systems has increased from 6.4% in 2000 to 14.5% in 2015 while that of wet cooling systems, including both closed-loop and open-loop cooling, has decreased accordingly.

There are also other official but non-mandatory guidelines for water-using practices in the coal power sector, such as ‘Guidelines for water saving in thermal power plants’ issued by the State Economic and Trade Committee, ‘China water conservation technology policy outline’ by the NDRC and ‘Water efficiency guide for key industrial sectors’ by the Ministry of Industry and Information Technology (Zhang et al 2016).

Some trade-offs need to be made regarding choosing cooling technologies. While replacing open-loop cooling systems with closed-loop ones reduces the power sector’s dependency on water supplies and thus enhances its resilience to extreme weather events (e.g. droughts), it also markedly increases the power sector’s consumptive water use and therefore competes with other water users, e.g. agriculture and domestic. Moreover, besides larger capital investment (for land and cooling towers), more water efficient technologies lead to lower power production efficiencies, which results in larger coal inputs and higher emissions, including carbon and other pollutants. Future infrastructure planning and investment need to consider those trade-offs prudently.

Although not considered in this study, upgrading boiler technology may also contribute to the power sector’s water savings. As Zhang et al (2016) has demonstrated based on field data in China, EGU’s with larger capacities are more water efficient. The reason is because larger EGUs tend to adopt more advanced boiler technologies, e.g. supercritical, with higher efficiencies, which means more heat is converted from the primary energy carrier, e.g. coal, to electricity, and therefore less residual heat needs to be dissipated by cooling water. Nonetheless their effects on water use are much smaller compared with plant types and cooling technologies (Macknick et al 2012).

3.2.4. Uncertainties in the driver effects attribution
Uncertainties resulted from the decomposition method are illustrated in figure 5 using water...
Figure 4. Historical changes of cooling technology configurations in China’s six regional grids.

Figure 5. Uncertainties in attributing driver effects of the power sector’s water withdrawals in China.
withdrawal as an example. It can be seen that the average uncertainties in attributing the effects of population change, demand change, energy structure change and water intensity change are $[-18.0\%, +16.0\%], \pm 7.1\%, [-20.2\%, +18.9\%]$ and $\pm 22.8\%$, respectively. It is the highest for population factor in the northwest from 2000 to 2005, $[-35.6\%, +36.5\%]$, and the lowest for demand factor in the north from 2010 to 2015, $[-0.36\%, +0.31\%]$.

In absolute terms, different ways of accounting the joint terms could result in uncertainties of $\pm 0.08$, $\pm 0.27$, $\pm 0.07$ and $\pm 0.24$ billion $\text{m}^3$ of water withdrawals triggered by the changes of population, power production per capita, energy structure and water withdrawal intensity, respectively.

4. Conclusions

Water scarcity has already hindered China’s energy development, manifested by plans to build coal-to-liquids plants being abandoned in 2008. Qin et al (2015) and Liao et al (2016) have also demonstrated that, with uncoordinated policies, power production may violate industrial water policies in the future, on both national and regional scales. While previous studies have revealed the current status and future contingencies of China’s water-for-electricity nexus issues, this study has, for the first time, shed light on its past trajectories as well as driving factors on a regional level.

Both water withdrawal and consumption have more than tripled in China’s power sector from 2000 to 2015 and this study shows that power production per capita was the primary force driving the power sector’s water use increases. However, China’s national average power production per capita is still low, amounting to only 4153 KWh in 2014 and ranked around 70th in the world, against 7995 KWh in OECD countries and 12987 KWh in the United States (World Bank 2017). Furthermore, we have demonstrated that a series of China’s policies primarily aimed to reduce carbon emissions and other air pollutants have generated co-benefits of offsetting the power sector’s water use increases. Although inter-regional power transmissions were small in the past and thus not considered in this study, China has embarked on building long-distance power transmission lines, especially ultra-high voltage ones, to facilitate transmitting electricity generated by renewable energies in inland regions to densely populated coastal regions. Their possible effects on the national as well as regional water resources need to be further researched.

Through studying the historical trajectories and driving factors, we highlight two features of China’s water-for-electricity nexus: its geographical disparities and potential cross-sectoral conflicts or synergies. How to take these geographical differences into account prudently, and to maximize potential synergies and minimize conflicts remain pivotal for future policy formulations and implementations, as well as infrastructure planning and investments in both power and water sectors in China for a sustainable future.

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