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# China's energy-water nexus – assessment of the energy sector's compliance with the “3 Red Lines” industrial water policy

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## HIGHLIGHTS

- A whole systems analysis of current and future water used for energy is presented.
- The energy sector's compliance with the “3 Red Lines” water policies is assessed.
- Future energy plans could conflict with the “3 Red Lines” industrial water policy.
- Water used for energy is highly dependant on technology choices.
- Co-benefits and trade-offs between future energy and water plans are identified.

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## ABSTRACT

Increasing population and economic growth continue to drive China's demand for energy and water resources. The interaction of these resources is particularly important in China, where water resources are unevenly distributed, with limited availability in coal-rich regions. The “3 Red Lines” water policies were introduced in 2011; one of their aims is to reduce industrial water use, of which the energy sector is a part. This paper analyses current water withdrawals and consumption for all energy processes and assesses the sector's compliance with the industrial water policy under different scenarios, considering potential future policy and technological changes. The results show that future energy plans could conflict with the industrial water policy, but the amount of water used in the energy sector is highly dependant on technology choices, especially for power plant cooling. High electricity demand in the future is expected to be met mainly by coal and nuclear power, and planned inland development of nuclear power presents a new source of freshwater demand. Taking a holistic view of energy and water-for-energy enables the identification of co-benefits and trade-offs between energy and water policies that can facilitate the development of more compatible and sustainable energy and water plans.



## 1. Introduction

Energy and water resources are closely interlinked and are both critical to the development of human society. Water is required for the production of energy, and energy is needed for the supply, treatment, desalination and distribution of water resources. Hoff. (2011) emphasises the need for integrated resource planning for energy and water, which is becoming increasingly recognised by international institutions, national governments and businesses. However, energy and water policies are still mostly developed in isolation from each other (Hussey and Pittock, 2012; Siddiqi et al., 2013). China is a unique case study to assess the dynamic interactions between these resources and the policies related to them. The country has 22% of the world's population but only 6% of the world's freshwater resources (Guan and Hubacek, 2008). Some areas already suffer from severe water issues; the Chinese Academy of Sciences (2007) found that two-thirds of China's 669 cities have water shortages and up to 40% of rivers are severely polluted. Rapid economic development has seen the country's total primary energy production more than double between 2000 and 2010 (NBSC, 2011), with an energy profile dominated by coal. Growth of China's economy and its emerging middle class continue to drive the country's growing energy and water demands. The energy–water interaction is further intensified in China because the majority of coal reserves are found in the country's driest regions.

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Water constraints have already impeded energy developments in China, as plans to build dozens of coal-to-liquid (CTL) plants were abandoned in 2008 because of local water scarcity (IEA, 2012).

The Chinese government, recognising the importance of water to the country's socio-economic development, announced its most stringent water management plan to date in 2011, as part of the Central No 1. Document known as the “3 Red Lines” water policies. These policies were fully implemented in 2012 with targets on total water use, water use efficiency for industry and agriculture, and water quality improvements on a national as well as on a regional scale (i.e. river basins, provinces, cities and even counties), for 2015, 2020 and 2030. These policies aim to address China's regional imbalance in water availability, and to encourage the sustainable use of water resources. Liu et al. (2013) emphasise that the realisation of these goals will bring positive long-term benefits for China's water system.

The future development of China's energy landscape has global implications and is the subject of great academic, policy and media attention. To meet growing energy needs and the pressure to reduce greenhouse gas emissions, China's future energy plans include an increase in the proportion of natural gas, nuclear and renewables in the energy mix, as well as encouraging energy efficiency improvements. However, Pan et al. (2012) and Wang et al. (2014) emphasise that coal is still expected to play a significant role. Recognising the need to reconcile coal use and water supply, the Chinese government added the “water-for-coal” plan to the “3 Red Lines” water policies in 2013, requiring future large-scale coal projects in water scarce regions to be developed in partnership with local water authorities. This is significant progress, but other energy processes should also be considered in a wider “water-for-energy” plan. Given the interdependence between energy and water and the lack of full integration in future plans, the “3 Red Lines” industrial water policy may conflict with future energy plans. The purpose of this paper is to undertake a detailed analysis of the uses of water in the energy sector in order to understand this potential policy conflict. The following section evaluates previous research on water and energy, to define the specific questions that need to be addressed by this analysis.

### 1.1. Previous work – assessing the water use for energy

In recent years, literature on the water–energy nexus has increased, with most of the research integrating the two resources in terms of physical linkages, planning and policy. This demands a clear understanding of how energy processes use water, and methods for calculating the water impact of different energy technologies, as recommended by NETL (2011) and Hadian and Madani (2013). Most research and data on water-for-energy seem to derive from the United States, and focus on power generation.

Meldrum et al. (2013) and Macknick et al. (2012) have carried out comprehensive reviews of water withdrawal and consumption intensities for a range of power technologies. Macknick et al. (2012) focus on water use for the operational phase (cooling, cleaning and other process-related needs), whereas Meldrum et al. (2013) review life-cycle water use. Both papers found that the cooling of thermoelectric power plants is an intensive water use and that power generation from solar photovoltaic (PV) and wind turbines have the lowest water requirements. However, both studies highlight that for most generation technologies, estimates vary significantly and are based on few sources. There is general agreement in the literature (Mielke et al., 2010; Averyt et al., 2013; King et al., 2013) that there is a need for better quality data, which is collected and monitored consistently to allow more robust water-for-energy research.

It is important to understand the difference between water withdrawals and water consumption, as both are key indicators for assessing water use in the energy sector, especially in power generation. However, Macknick et al. (2012) stress that state agencies often do not use consistent methods or definitions in measuring water use by the energy sector. The literature is equally inconsistent; Grubert et al. (2012) use water consumption as a performance indicator for investigating the effect of switching from coal-fired to gas-fired power generation in the US, whereas Yu et al. (2011) consider water withdrawal when assessing coal-fired power generation in China. Meldrum et al. (2013) also note that reports often fail to specify whether it is withdrawal or consumption that is being analysed. This study classifies water withdrawal as water removed from the ground or diverted from a surface water source for use, and water consumption as that fraction of the water withdrawn that is removed from the immediate water environment (Kenny et al., 2009); for example, water that is evaporated from cooling towers.

Research on water use for fuel extraction and processing is included in life-cycle assessments of power generation. Meldrum et al. (2013) highlight that the operational phase dominates the life-cycle water use for most power generation pathways, and that for coal, natural gas and nuclear power, the fuel cycle contributes a small but non-negligible amount to total life-cycle water use. However, aside from these life-cycle assessments, there appears to be minimal literature on water used for the extraction and processing of energy sources, compared to studies on power generation. Mielke et al. (2010) and Williams and Simmons (2013) assess water use in the whole energy sector including water use for extraction and processing. Although water has always been understood to be a potential constraint for thermal power generation, its importance in fuel production processes is becoming more apparent (Mielke et al., 2010).

Water-for-energy nexus studies have been carried out in Spain, the Middle East-North Africa (MENA) region, Jordan and the United Kingdom as well as in the United States. It appears that data from the United States are often used when local data are unavailable; this applies for the United Kingdom (Byers et al., 2014) and the MENA region (Siddiqi and Diaz, 2011). These case studies of region-specific water-for-energy connections and stresses help to highlight the importance of carrying out water–energy analysis on a regional scale, as emphasised by Schnoor (2011).

The literature on water-for-energy in China is focused mainly on coal. Pan et al. (2012) provide China-specific quantitative information on water withdrawals, consumption, wastewater recycling and treatment for the various processes used within the coal industry, including coal extraction and power generation. An average water-use intensity figure is used for each coal industry process, but the effects of different technologies within each process are not considered. Pan et al. (2012) use these data to analyse future scenarios, and conclude that the compliance of the coal industry alone with the future industrial water policy would require the adoption of many water-saving measures.

Yu et al. (2011) use a technology-based, bottom-up model to assess how future policies and technological changes may affect the coal-fired power sector's coal consumption, water withdrawals, $SO_2$ and $CO_2$ emissions. The authors conclude that technology innovation is key to resource conservation, but acknowledge that technological maturity and high installation costs are likely bottlenecks. However, the additional technological detail and future scenario assessment by Yu et al. (2011) is only for coal-fired power generation and water withdrawals. Zhang and Anadon (2013) assess life-cycle water withdrawals, consumptive water use, and wastewater discharge in China's energy sectors, and their environmental impacts. This analysis has a strong spatial component highlighting provincial water usage, but does not include future assessments.

This review shows the need to consider all current and