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# Synergetic effects of water and climate policy on energy-water nexus in China: A computable general equilibrium analysis

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ABSTRACT

A unified policy framework for energy and water would be beneficial considering the high interdependence of the two resources in China. In this paper, a recursive dynamic computable general equilibrium model is established to examine the existence of synergetic effects within water fee policy and energy related climate policy, i.e. carbon tax, and provide insights for Chinese integrative policy-making. The results show that water fee can contribute to industrial water conservation, whereas its effect is limited under current water fee level. The adoption of a carbon tax in addition to it might further improve its water saving benefits. Furthermore, water fee can also promote the enhancement of China's emission reduction goal, and a higher carbon tax and water fee rate can achieve greater emission reduction effects. At this point, the synergetic spillover effects that water conservation benefits will be achieved simultaneously via the transition of industry into a more low-carbon form is critical for elaborating an effective strategy of environmental policy. Besides, our results suggest that giving priority to renewable power is regarded as the silver bullet to address the water and emission constraints on energy system, as it can optimize the water conservation benefits of emission reduction.

## 1. Introduction

As two fundamental resources that underpin socio-economic development and human well-being, water and energy are interdependent as the supply of one highly depends on the availability of the other (World Bank, 2017). This so-called energy-water (EW) nexus is particularly important in China, due to the fact that the spatial pattern of water availability in this country does not match that of energy endowment, which has presented a great challenge for energy system (Fan et al., 2017; Gu et al., 2017). Taking the “golden triangle area” in China as example, this region supports around 71% of the total coal production of China, while the share of water resource in this region is about 3.9% of China's total water resource in 2013. In the near future, according to the Energy Development Strategy Action Plan (2014–2020), China will build fourteen large-scale coal production bases across the country during the period of the 13th Five-Year Plan (2015–2020), to satisfy its surging energy demands (Shang et al., 2017). It will inevitably aggravate the tension between water and energy, given that most of the planned coal bases are located in arid or semi-arid regions.

In fact, when considering the interlinkage between energy and water, carbon dioxide ($CO_2$) emission is also a subject that cannot be ignored, as China is the largest energy-related $CO_2$ emitter worldwide. It is estimated that in 2014, the energy-related $CO_2$ emission of China has reached 8.6 billion tones, accounting for 28% of the global total emission (IEA, 2016). Great emission reduction pressure will promote the transition of the Chinese energy system into a more low-carbon form. And the effects that the transition could have on energy system in the context of total control and structure improvement can also impose significant implications on EW nexus.

The Chinese government has regarded water, energy and associated emission issues as highly important. Over the years, it continues to develop policies and targets to address water scarcity and climate change. In 2011 the government proposed the “most stringent” water resource management plan, known as the “3 Red Lines”, with targets set forth on water use, water use efficiency and water pollution. And its fulfillment is further guaranteed via the implementation of the water fee rate policy by 2015 (NDRC, 2013). At the same time, China also takes an active response to climate change with a series of ambitious emission reduction targets (Liu et al., 2017). According to its Intended Nationally Determined Contributions (INDC), it committed to lower its

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$CO_2$ emissions per unit of GDP by 60–65% from 2005 level (NDRC, 2015). To accomplish the emission reduction target, the major economic approach, and the most plausible way as well in China, is to adapt carbon pricing policy i.e. putting a price on carbon either through a carbon tax or a cap-and-trade scheme (Liu and Lu, 2015).

However, with respect to those significant steps that China has taken, e.g. on-going water fee policy and future carbon pricing policy, corresponding decision and policy making processes are usually undertaken in isolation by various departments. This indicates that energy and emission issues have not been taken into account when most water policies have been designed, and vice versa. Thus when considering the intricate interlinkage among water, energy and emission, it is logical to pose the following questions. First, what the spillover effects of water fee policy (or carbon pricing policy) could have on energy, emission (or water) and the fulfillment of corresponding targets? Second, how should we benefit from the spillover effects in the context of bringing insights into guiding coherent policy making? The answers to these questions can bring some insights for understanding EW nexus from perspective of policy making, and help to work towards a scientific water scarcity management and climate change mitigation pathway via integrative resource governance in China.

## 2. Literature review

Economic growth, coupled with population expansion and rapid urbanization, will impose great pressure on water and energy resources. Given the concerns on water and energy crisis, a growing emphasis, particularly by scholars, has been placed upon the nexus thinking of the two resources with respect to utilization pattern and corresponding policy making, which promises renewed opportunities to create pathways for sustainable resource management (Scott et al., 2011; Qin et al., 2015).

Many empirical studies have made quantitative analysis of the EW nexus issues. From energy provision, research usually attempts to figure out the gaps between limited water endowment and increased water demand for energy extraction, processing and conversion, including fossil fuel production (Jenner and Lamadrid, 2013; Pan et al., 2012; Shang et al., 2018;), bioenergy production (Gerbens-Leenes et al., 2012; Pacetti et al., 2015), and power generation (Ackerman and Fisher, 2013; Li et al., 2012; Scanlon et al., 2013), highlighting the water guarantee in energy system sustainable development. For example, Pan et al. (2012) illustrated the major challenges existing in the coal industry in China from a supply chain point of view, finding that without implementing effective policy to stress water management and water-saving measures, the water requirement in the coal industry could probably exceed local water carrying capacity in the near future. Byers et al. (2014) quantified the water use of the UK electricity sector under six decarbonization pathways to 2050, indicating that in terms of water saving benefit, renewable energy power generation is preferred to carbon capture and storage (CCS) and nuclear power in future energy development strategy. From the water provision, the mostly emphasized issue is the increased energy consumption and GHG emissions during the water supply and treatment processes (Cheung et al., 2013; Siddiqi and Anadon, 2011; Silva Vieira et al., 2013).

In fact, most of these works have shown their great ambitions to achieve policy coherence based on their quantification and examination results. However, the literature investigating how policies change and the subsequent effect on practice can affect the dynamic development of water-energy nexus is not extensive. Furthermore, these contributions do mainly address policy issues relevant to energy, such as energy resource tax (Zhou et al., 2016), industrial energy conservation policy (Gu et al., 2016, 2014), as well as emission standards policy on energy sectors (Wang et al., 2018). For example, Zhou et al. (2016) built a multi-sectoral dynamic CGE model to study the impacts of energy tax on energy and water resources, concluding that the energy tax would significantly decrease the water required for energy production and make great contribution to the accomplishment of the "3 Red Lines" target. In contrast, the effects of water policy on both resources, as well as the implications of coupling processes between the two domain policies can impose on integrative policy making, are still largely unexplored. Given that developing plan and policy in the two fields are still formulated in isolation, understanding the spillover effects that the two domains policies may have on both resources is of great importance in this country. Within this context, this paper makes a three-fold contribution to existing literatures:

(1) We attempt to investigate the EW nexus issues from the perspective of policy making, via the examination and quantification of the subsequent spillover effects that the existing water policy and future climate policies may have on both two resources in China.
(2) A multi-sector recursive dynamic CGE model is established based on China's latest 2012 Input-output Table. In order to conduct a comprehensive and dynamic assessment for China's EW nexus, we make a detailed disaggregation of energy industry into 10 specific sectors. Meanwhile a water module is also integrated with the CGE model based on exhaust data collection and process, which enables us to have a deep understanding of water use at sector-level.
(3) The total seven scenarios, including business as usual (BAU) scenario, two water fee scenarios and four carbon tax involved mixed scenarios are set, whereby it can help to understand how to optimize the interconnections within the two domain policies and identify the leverage point to manage the co-benefits and trade-off for the goal of integrative policy making.

## 3. The CGE model

Referring to Fan et al. (2015); Liang et al. (2007); Löfgren et al. (2001), this paper applies a recursive dynamic CGE model to make quantitative assessment on the effects of water policy and carbon pricing policy as well as the interconnection between the two policies.

### 3.1. The production module

For domestic goods, the module assumes that capital, labor, natural resource, energy, and other intermediate inputs will be used to produce output under the minimizing cost constraint. The optimal combination of various inputs can be obtained by the following equations:

$$\min \sum_i P_i \cdot X_i \tag{1}$$

$$s.\ t{:}\ Z = A\left(\sum_i \alpha_i X_i^{\rho}\right)^{\frac{1}{\rho}} \tag{2}$$

where $X_i$ is the input $i$; $P_i$ is the corresponding price; $Z$ is the output level; $A$ is the is the overall transformation parameter applied to all inputs; $\alpha_i$ is share parameter of $X_i$; $\rho$ is a coefficient related to the elasticity of substitution $\sigma$ ($\rho = (1-\sigma)/\sigma$).

Following Fan et al. (2014, 2015) and Liang et al. (2007), the model in this paper includes four types of sector: ordinary sectors, sectors with natural resource inputs, energy processing sectors and the clean power generation sectors. The production structure of ordinary sectors is represented by a six-layer, nested CES function, as depicted in Fig. 1. The top layer of the nested structure comprises the intermediate inputs and a composite factor of labor, capital, and energy. The second layer determines the producer's demand for labor and the composite commodity of capital and energy. In the third layer, the capital-energy bundle is disaggregated into energy composite and capital, and the energy composite is disaggregated into fossil energy bundle and electric power in the fourth layer. In the fifth layer, fossil energy comprises five fossil fuel inputs in the form of Cobb-Douglas functions, while the electricity bundle divided into thermal power and clean power, the