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Evaluating the water footprint of the energy supply of Liaoning Province, China: A regional input–output analysis approach

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HIGHLIGHTS

- We assess the water footprint of energy supply (WFES) for Liaoning Province, China.
- The WFES for 2002 was 854 million m^3, with 47% used for electricity and heating.
- External sources accounted for 80% of the WFES and 47% of the energy supply.
- Without energy imports, water resource withdrawal would increase from 86% to 91%.
- Effective water resource management is important for regional energy security.

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ABSTRACT

Water and energy are important resources for regional economies and are inextricably and reciprocally linked. Global water and energy demand will increase significantly by 2030 while climate change will worsen water availability. Thus, it is important to ensure a sustainable energy supply despite the increasing severity of water resource constraints. Numerous studies have analyzed water requirements to produce energy from production perspectives. However, energy is generally supplied by both internal and external producers. Thus, it is necessary to consider the availability of water to produce energy from consumption perspectives also. We evaluate the water footprint of the energy supply of Liaoning Province, China. We apply the standard top-down approach using an input–output framework. We estimate the water footprint of the energy supply of Liaoning Province at 854 million m^3 in 2002, with 47% of water used for electricity and heating. Our results reveal that energy supply could depend on water resources in neighboring provinces; external producers met 80% of the water footprint of energy supply, although only 35% of energy supply was imported. If Liaoning Province decreased its external dependency, withdrawal of available water resources within the province would increase from 86% to 91%. To guarantee future regional energy security, it is important to manage water resources effectively through water-efficient electricity generation and by allocating water resources among sectors.

1. Introduction

Both water and energy are important resources for sustainable development and are inextricably and reciprocally linked (Scott et al., 2011; Siddiqi and Anadon, 2011). Furthermore, global demand for water and energy will rise by 40% and 50%, respectively, by 2030 (National Intelligence Council, 2012). By 2035, global water withdrawals for energy production will increase by more

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than 20%, while global water consumption is set to rise by 85% compared to 2010 (International Energy Agency, 2012). Therefore, it is possible that energy production will become a big contributor to global water stress in the future.

At the same time, it is believed that accessibility to water resources will worsen; climate change analysts suggest that the severity of existing weather patterns will intensify, with wet areas getting wetter and dry and arid areas becoming more so (National Intelligence Council, 2012). Therefore, it is likely that future water availability will have more regional gaps due to the global changes in water resource distribution.

The abovementioned scientific knowledge suggests that there is an important political question about energy, namely, can we continue to supply energy sustainably, especially at the regional scale, under increasingly severe water availability constraints? Thus far, numerous researchers have investigated questions concerning water for energy from production perspectives, thus providing much-needed information regarding the parameters of water requirements to produce energy. For example, about 1 m^3 of water is consumed to produce 1 GJ of crude oil (Gleick, 1994), and 1 GJ of hydropower generation consumes 22 m^3 of water (P.W. Gerbens-Leenes et al., 2009a).

However, the impact on water resources differs by region because water stress differs by region (Pfister and Hellweg, 2009; Ridoutt and Pfister, 2010). Moreover, energy supply systems have regional differences depending on the availability of resources, such as types of primary energy (renewable/nonrenewable), levels of energy production technology, and energy transportation systems (e.g., pipelines for natural gas and delivery of coal by vehicles). National (or regional) energy consumption is typically covered by both domestic (or internal) and foreign (or external) energy producers. Therefore, to analyze water for energy from consumption-based perspectives, it is important to consider both water for energy supply and water for energy production.

To evaluate water for energy supply, we adopt the water footprint analysis approach. The water footprint has been investigated using various methods (Feng et al., 2011; Hoekstra and Chapagain, 2008) based on consumption perspectives, and it encompasses both domestic production and imported commodities for production (Hoekstra and Chapagain, 2008; Lenzen, 2009). This approach is utilized mainly for calculating the water footprint of water-intensive commodities, such as crops and other agricultural products, and thus, in this study, we apply the method to energy commodities.

Our objective in this study is to develop an approach for evaluating the water footprint of energy supply. At the same time, we conduct a regional analysis taking account of current regional differences in energy supply systems and water availability. Moreover, we consider implications for energy policy so that local decision makers and stakeholders can effectively manage their water resources. We focus our analysis on Liaoning Province, one of China's economically important provinces, which faces serious water stress.

The rest of the paper is organized as follows. First, Section 2 profiles the study area and explains our method for calculating the water footprint of energy supply. It also provides a literature review of previous studies on water for energy and various methods used for water footprint analysis. Section 3 shows the results, and Section 4 discusses them. Finally, Section 5 provides policy implications for energy and water security and concludes with future tasks for the regional water footprint analysis of energy.

2. Methods

2.1. Description of the study area

We select Liaoning Province in northeast China as our case study area (Fig. 1). It covers an area of 148,000 km^2, and as of 2010, had a population of 43.75 million people (Bureau of Statistics Liaoning Province, 2011). Liaoning Province is one of China's most heavily industrialized provinces and contains many large manufacturing companies. In addition, Liaoning Province is an economically important province in China. It is ranked seventh among all Chinese provinces in terms of the gross regional product, which was 1846 billion Chinese yuan (301 billion US dollars) in 2010 (Bureau of Statistics Liaoning Province, 2011). Liaoning Province has relocated many high polluting companies to “eco-industrial parks,” where improved, environmentally friendly infrastructure exists due to the implementation of the “Revitalizing the Old Northeast Industrial Base” program launched in the early 2000s by the Chinese central government. Both industrialization and urbanization are projected to increase in this region, representing a microcosm of the overall socioeconomic shifts occurring throughout China (Dong et al., 2013). Given its industrial prowess, Liaoning Province consumes large amounts of energy resources. In

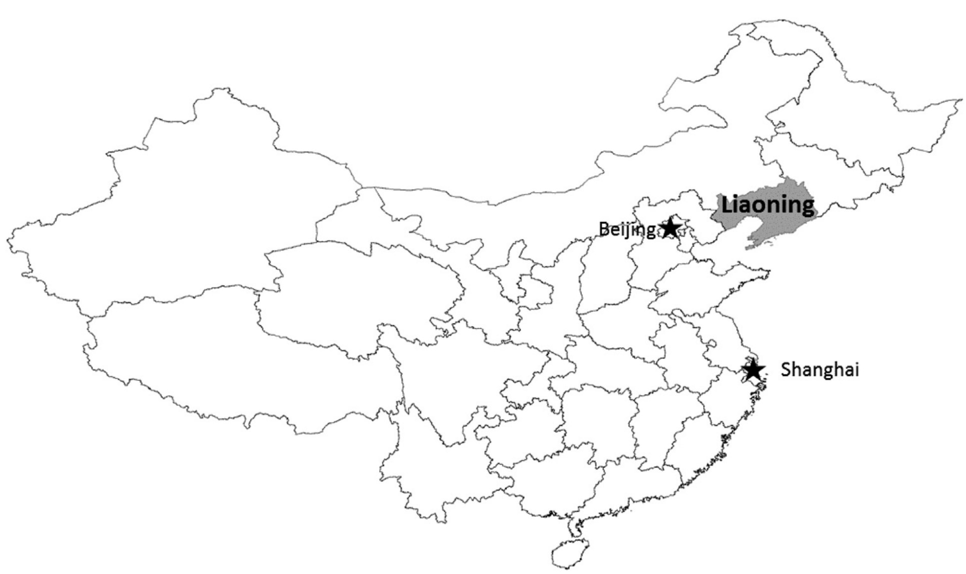

Fig. 1. Location of Liaoning Province.