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Energy and water conservation synergy in China: 2007–2012

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ABSTRACT

Energy and water issues are interrelated and have significant impacts on the economy. The amount and intensity of energy and water consumption must be controlled, which was clearly stated in the “11th Five-Year” Plan and “12th Five-Year” Plan. The energy-water nexus is a useful approach to integrate economic sectors. Energy production consumes large inputs of energy and water, while producing most of the energy required by other sectors. This synergy between energy conservation and water saving in energy sectors is intricate. This study assesses the synergistic effect between energy conservation and water saving that has been achieved by energy sectors in China during the 2007–2012 period. The research results suggest that energy sectors have completely achieved 12.40×10^8 m^3 water saving through energy conservation and 1.12×10^6 tce energy conservation through water saving. Coal, oil and gas production mainly consumed water in indirect ways, while electricity generation primarily consumed water in a direct way. The synergistic energy conservation of the electric power sector was significant and was much larger than that of the coal production sector as well as oil and gas production sector. Prominent water saving can be obtained through improved energy conservation in China’s energy sectors.

1. Introduction

Energy and water resources are critical to the economic development and social stability of China (Hamiche et al., 2016; Wang et al., 2016; Zhang and Vesselinov, 2016; Hu et al., 2016). Promoting energy and water conservation has always been important policy goals in China. For example, a 30% decline in water consumption per industrial added value and a 16% reduction in energy consumption per unit of GDP were expressed in the “12th Five-Year” Plan. The “13th Five-Year” Plan proposed dual control actions against the total amount and intensity of energy and water resources. Promoting energy and water conservation and maintaining an annual GDP growth rate of 6.5% (outline of “13th Five-Year” Plan) simultaneously have become major challenges for the sustainable development of China.

Use of energy and water resources has been significantly affected by specific limitations related to individual conditions as well as the constraints caused by their interactions (Scott et al., 2011; Siddiqi and Anadon, 2011). Energy production requires substantial amounts of water inputs (Qin et al., 2015), specifically in the production of oil, natural gas, coal, and electricity (Bravo, 2016; Yune et al., 2016; Zhu et al., 2015). Likewise, utilization of water resources requires considerable energy input (Bennett, 2015), especially for exploitation, transportation and treatment (Gleick et al., 2002; Vilanova and Balestieri, 2015; Thiel et al., 2015; Singh and Kansal, 2016). These illustrate the intertwined relationship between energy and water resources (Rothausen and Conway, 2011; Wang et al., 2015).

The energy-water nexus plays an important role in energy and water conservation, since it was first conceptualized in early 1990s (Gleick, 1994). One essential component of the energy-water nexus is their interconnections. Synergy exists in water and energy systems at different levels (Bennett, 2015; Yang and Chen, 2016; Nguyen et al., 2014). Gu et al. (2014) found that, during the “12th Five-Year” Plan, the industrial sectors indirectly achieved water saving of 13.06×10^8 m^3 by reducing energy consumption.

Among all conceivable sectors, the energy-water nexus is unique. Energy sectors support the socio-economic development by generating energy used for manufacturing, services, and welfare, while consume significant amounts of energy and water at the same time (DeNooyer et al., 2016; Bravo, 2016). Energy generation can be very water intensive (i.e. cooling water for thermal power plants, etc.) and energy intensive (poor efficiency in turbines, refineries and other conversion technologies). Consequently, energy and water conservation are particularly important in energy sectors, with prominence allocated to their synergistic effect.

Existing research has chiefly emphasized accounting of energy and water consumption, essentially insinuating that merely one-way

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relationship between energy conservation and water saving have been analyzed. China has promoted energy and water conservation in both the "11th Five-Year" Plan and "12th Five-Year" Plan, where energy-conservation policies in major industrial sectors have achieved significant synergistic water saving. However, water consumption data is usually monetary and limited to commercial water in an input-output table (Gu et al., 2016), so these data can be significantly affected by price.

To omit the impact of price on the results, the physical quantities of water and energy consumption of each sector in different years are uniformly applied in this paper. Most studies used total energy consumption for each sector and overlooked the water consumption intensity differences of various energy forms (electricity, coal, oil, etc.). It can result in significant shortcomings because different sectors consume disparate energy forms, and the disparity of water consumption of coal and electricity can be up to 97 times (Gu et al., 2014). Other research focused on the synergistic effect of one specific energy consumption or generation on water use, like coal consumption (Nguyen et al., 2014), electricity consumption (Li et al., 2013), wind power generation (Li et al., 2012; Yang and Chen, 2016) and thermoelectric power generation (Liao et al., 2016). However, sectors consume many forms of energy, so such studies cannot reflect the whole synergistic effect between energy and water in sectors. In this paper, various types of energy are distinguished to assess synergistic effect between energy and water conservation comprehensively.

The goal of this paper is to determine if energy sectors that directly generate energy have achieved energy and water conservation. The synergistic effect between the two resources is also examined. The results not only involve the self-development of energy sectors, but also are closely related to the national energy development plan and industrial structural adjustment.

2. Method and data

2.1. Method

The input-output analysis (IOA) was first put forward by Leontief (1936). IOA modelling can reflect interdependence between production and distribution of various economic sectors. IOA method was frequently applied to assess the direct and indirect material flows of different economic activities within environmental analysis (Liang et al., 2017; Wu and Chen, 2017). Specifically, IOA has been widely used to account for resource consumption and pollution transfer, such as energy consumption (Tang et al., 2016; Sun et al., 2017), water consumption (Wang and Chen, 2016; Liu et al., 2017) and carbon emissions (Xu et al., 2017). For water-energy interconnections, some researchers used IOA model to calculate the synergy between energy conservation and water saving in China's economic sectors (Gu et al., 2014; Okadera et al., 2015; Borda et al., 2015). On the other hand, the IOA method has some weaknesses in material flow accounting. Calculations based on competitive IO tables ignore the differences between domestic products and imports. This may result in overestimation (Su and Ang, 2013). The level of sector aggregation can also have impacts on the results obtained (Su et al., 2010). IO tables are released every five years, if the year of other data is inconsistent with that of the IO table, the estimates of material flow can be affected. The data used in this paper were collected and processed to match the year of IO table during the research period. In addition, this study chose IO tables and conducted sectoral aggregation according to the existing studies focusing on energy-water assessment (Liang et al., 2012, 2014; Wang et al., 2013; Guan et al., 2014; Okadera et al., 2015; Wang and Chen, 2016; Gu et al., 2016) and data availability, and some improvements have been made at some specific steps to increase accounting accuracy and complete our research.

To quantify the interaction between energy and water conservation in energy sectors, the synergistic water-saving effect of energy conservation as well as the synergistic energy-conservation effect of water saving in energy sectors during the 2007–2012 period has been calculated in this study. Firstly, the coefficients of energy and water consumption are calculated using IO Table 2012. The mathematical expression of direct consumption coefficient is as follows:

$$a_{ij} = \frac{x_{ij}}{x_j}(i, j = 1, 2, \ldots, n) \tag{1}$$

Where, the direct consumption coefficient a_{ij} denotes the products of sector i directly consumed by sector j to produce unit product; x_{ij} denotes the product of sector i put into sector j; x_j denotes the output of sector j.

The direct consumption coefficient reflects the input-output relations between sector j and the directly related sector i. The products of other sectors consumed by sector j for unit output need to be calculated to reflect both the direct and indirect relations between sector j and the remaining sectors.

$$b_{ij} = a_{ij} + \sum_{k=1}^{n} a_{ik}a_{kj} + \sum_{s=1}^{n}\sum_{k=1}^{n} a_{is}a_{sk}a_{kj} + \ldots(i, j = 1,2,\ldots,n) \tag{2}$$

Where b_{ij} denotes the products of sector i completely consumed by sector j to produce a unit of product; A and B represent the matrix composed of a_{ij} and the matrix composed of b_{ij}. The above equation can be expressed as:

$$B = A + A^2 + A^3 + \ldots \tag{3}$$

Eq. (3) can further expressed as:

$$B = (I - A)^{-1} - I = [b_{ij}] \tag{4}$$

Where I denotes the identity matrix; $(I - A)^{-1}$ is a Leontief inverse matrix; b_{ij} denotes the total (indirect and direct) demand on the output of sector i for the unit final products of sector j; $[b_{ij}]$ is a complete consumption matrix.

The direct energy consumption coefficient reflects the direct energy consumption volume for producing unit product; The direct water consumption coefficient reflects the direct water consumption volume for producing unit product. The calculation of the two coefficients above can be expressed as follows, respectively:

$$\omega_i = w_i/x_i \tag{5}$$

$$\varepsilon_i = e_i/x_i \tag{6}$$

Where w_i denotes the amount of water directly consumed by sector I, unit: m^3; e_i denotes the amount of energy directly consumed by sector i, unit: *ton* for coal and oil consumption, kWh for electricity consumption; x_i is the output of sector i; ω_i denotes the direct water consumption of sector i to produce unit product, unit: m^3/CNY; ε_i denotes the direct energy consumption of sector i to produce unit product, unit: *ton/CNY* for coal and oil consumption, kWh/*CNY* for electricity consumption.

Sectors consume resources in a direct way, but also indirectly consume resources through other sectors in the production process. The complete resource (energy and water) consumption coefficients are calculated by multiplying the direct resource consumption coefficients by the coefficients in complete consumption matrix:

$$CW_j = \sum_{i=1}^{n} \omega_i b_{ij} \tag{7}$$

$$CE_j = \sum_{i=1}^{n} \varepsilon_i b_{ij} \tag{8}$$

Where CW_j is the complete water consumption coefficient, which denotes the water consumption of all sectors for producing products put into sector j for unit product j, unit: m^3/CNY; CE_j is the complete energy consumption coefficient, which denotes the energy consumption of all sectors for producing products put into sector j for unit product j, unit: *ton/CNY* for coal and oil consumption, kWh/*CNY* for electricity