Driving Forces Analysis of Water Consumption in the Energy Production Process in China Based on the LMDI Method

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Abstract
Energy shortage and water stress are two major environmental pressures during the rapid economic development and urbanization processes. In China, Coal-based energy excavation and treatment processes consume large amounts of water resource. Obtaining a clear understanding of water consumption in the energy production process plays a critical role in addressing the problems of energy shortage and water scarcity. The Logarithmic Mean Divisia Index (LMDI) method can reveal the driving forces behind water consumption changes in energy production. The results show that the growth of population and GDP per capita were dominant factors driving water consumption changes, while the improvement of consumption intensity and structure were main inhibiting factor on water consumption growth. The results may provide insights for synergetic management to alleviate the pressure caused by excessive water and energy consumption.

Keywords: Driving forces; energy; water; Logarithmic Mean Divisia Index; China

1. Introduction
Energy shortage and water scarcity both are main resource crisis globally and they linked inextricably. And water resource is consumed in almost all processes of energy production, such as coal washing, thermal plant cooling, power production and so on [1]. Expending the scale of energy exploitation process consumes a large number of water resource, which in turn aggravates the water scarcity problems. Considering that both water and energy are the key resources to maintain the sustainability development of the urban economy and environment, detecting the synergetic effects of water and energy consumption and figuring the driving forces are essential to enact appropriate management strategy [2].

Decomposition methods can quantify each driving forces to reveal the linkages between water and energy consumption [3-8]. Structural decomposition analysis (SDA), index decomposition analysis (IDA) and production-theoretical decomposition analysis (PDA) are used to identify the driving forces behind the effects as the common three methods. All of the three techniques have been widely employed to identify the influences of different driving forces on the overall change in energy use and water consumption. Logarithmic Mean Divisia Index (LMDI) method is most-extensively one in IDA methods. LMDI method can effectively reveal various impact factors that affect changes with no residual term [9]. Chong et al. (2017) analyzed the driving factors of energy consumption of Guangdong Province using LMDI method [10]. Liu et al. (2018) applied a joint decomposition method of PDA and IDA to study the driving factors of China’s energy consumption [11]. Similarly, Li et al. (2017) determined the influencing factors of water footprint via LMDI [12]. Based on the above, for the study of water consumption in energy production process, the LMDI method can reveal the driving force behind water consumption increase in energy production, in order to formulate effective measures to alleviate water pressure and energy pressure.

In this paper, LMDI method is used to account for diving forces of water consumption in the energy production process from 2005 to 2015. The study included water consumption caused by five energy production processes: raw coal-related water, thermal
power-related water, hydropower-related water, natural gas-related water, crude oil-related water. The total effect of water consumption changes is decomposed into four driving factors embracing industrial structure effect, industrial water consumption intensity effect, economic activity effect and population scale effect. The promoting factors have positive effects on the increase of water consumption in energy production process, and the inhibiting factors are opposite. Identifying the main water-consuming links in the energy production process can help alleviate the pressure of water shortages and provide rational suggestions for energy efficient production in future.

2. Paper Structure

2.1 Organization Structure

The rest of the paper is organized as follows: Section 2.2 illustrates the methodology and data sources; results and discussions are shown in Section 2.4.

2.2 Material and methods

Modified Logarithmic Mean Divisia Index (LMDI) method can be used to decompose the total effect of water consumption in the energy production process to different driving factors with no residues generation. According to Kaya equation, the LMDI method used to decompose water consumption is expressed as follows:

\[ W = \sum_i \frac{w_i}{W} G P = \sum_i S_i TEP \]  

where \( W \) represents the total water consumption in the energy production process; \( W_i \) is the water consumption of ith energy, where \( i=1,2,...,5 \), representing thermal power, hydropower, natural gas, raw coal, crude oil respectively; \( G \) represents gross domestic product; \( P \) is population. \( S_i \) denotes the water consumption structure, it is equal to the ratio of water consumption of ith energy to the total water consumption; \( T=(W/G) \) denotes water efficiency; \( E \) denotes economic activity.

\[ \Delta W = W^T - W^0 = \Delta W_{str} + \Delta W_{eff} + \Delta W_{eco} + \Delta W_{pop} \]  

where the superscripts \( T \) and \( 0 \) are the final year and benchmark year, respectively. \( \Delta W_{str} \), \( \Delta W_{eff} \), \( \Delta W_{eco} \) and \( \Delta W_{pop} \) are industrial structure effect, industrial water consumption intensity effect, affluence effect (per capita GDP effect), and population effect, respectively, denoting the contribution of change of industrial structure, change of water consumption intensity, change of economic activity, and change of population from base year \( 0 \) to year \( T \). The degree of each effect contributes to the change of total water consumption in the energy production process was calculated by the following equation:

\[ \Delta W_{str} = \sum_i \frac{w_i^T-w_i^0}{w_i^0} \ln \frac{S_i^T}{S_i^0} \]  

\[ \Delta W_{eff} = \sum_i \frac{w_i^T-w_i^0}{w_i^0} \ln \frac{p_i^T}{p_i^0} \]  

\[ \Delta W_{eco} = \sum_i \frac{w_i^T-w_i^0}{w_i^0} \ln \frac{g_i^T}{g_i^0} \]  

\[ \Delta W_{pop} = \sum_i \frac{w_i^T-w_i^0}{w_i^0} \ln \frac{p_i^T}{p_i^0} \]  

2.3 Data Description

The 2012 China MRIO table including 30 provinces, excluding Tibet, Taiwan, Hang Kong and Macau, is used (Mi et al., 2017). Energy data is obtained from China Emission Accounts & Datasets (CEADs) in year of 2012 (CEADs, 2016). The ratio of water consumption for each kind of energy source is obtained from the study of Zhu et al. (2015)[13].

2.4 Results

2.4.1 Driving forces of the changes of total energy production-related water consumption

From 2012 to 2015, Chinese water consumption has increased slowly. As shown in Fig. 1. After the amount of water consumption in 2012-2013 first decreased and then increased, the current water consumption showed a steady downward trend.

Fig. 1. The changes of total energy production-related water consumption.

Fig. 2. Driving factors for total energy production-related water consumption change.

Table. 1. Contributions of driving forces of the changes of total energy production-related water consumption(10^9m^3)

According to Fig.2 and Table.1, the economic activity and population were the dominate factors contribute to the changes water consumption. The water consumption intensity and industrial structure were the inhibiting factors, but industrial structure effect and water consumption intensity effect played as promoting factors in 2013, it may be due to factors that are unsuitable during the industrial transformation process. Meanwhile, the major contributing factor was per capita GDP and the major inhibiting factor was industrial water consumption intensity.

2.4.2 Driving forces of the changes of raw coal-related water consumption

Fig. 3. Driving factors for raw coal-related water consumption change.

Table. 2. Contributions of driving forces of the changes of raw coal-related water consumption(10^8m^3)
As shown in Fig.3 and Table.2, for water consumption changes in raw coal production process, the affluence effect and population effect were promoting factors for water consumption increase from 2012 to 2015. The industrial structure played as the inhibiting factors in 2012 and 2013, and then change to be the promoting factors in 2014 and 2015. The industrial structure effect always played as inhibiting factor except in 2013. According to the above information, the water use situation in the raw coal industry is gradually improving.  

2.4.3 Driving forces of the changes of thermal power-related water consumption  

Fig. 4. Driving factors for thermal power-related water consumption change.  

Table. 3. Contributions of driving forces of the changes of thermal power-related water consumption($10^6$m$^3$).  

As shown in Fig.4 and Table.3, for water consumption change in thermal power production process, the economic activity contributed the increase of water consumption and population contributed the decrease of water consumption from 2012 to 2015. The main inhibiting factor was industrial water consumption intensity effect, but it played as promoting factor in 2013. The industrial structure effect was similar to the intensity effect, but it played less importance in inhibiting the change of thermal power.  

2.4.4 Driving forces of the changes of hydropower-related water consumption  

Fig. 5. Driving factors for hydropower-related water consumption change.  

Table. 4. Contributions of driving forces of the changes of hydropower-related water consumption($10^6$m$^3$).  

As shown in Fig.5 and Table.4, for water consumption change in hydropower production process, the economic activity and population were the promoting factors changing water consumption from 2012 to 2015. The water consumption intensity factor in hydropower production process was the most significant inhibiting factor, even it also acted as promoting effect for water consumption change in 2013. Structure effect changes from the original inhibiting factor in 2012 and 2013 to the promoting factor in 2014 and 2015 and the driving influence of it was gradually weakening with the transformation of the industry.  

2.4.5 Driving forces of the changes of natural gas-related water consumption  

Fig. 6. Driving factors for natural gas-related water consumption change.  

Table. 5. Contributions of driving forces of the changes of natural gas-related water consumption($10^6$m$^3$).  

As shown in Fig.6 and Table.5, for water consumption change in natural gas production process, the economic activity and population were still the promoting factors changing water consumption from 2012 to 2015. Meanwhile, the major contributing factor was per capita GDP and the major inhibiting factor was the water consumption intensity. The trend of industrial structure of natural gas-related water consumption change was similar with hydropower-related water consumption change, it is due to both of them are clean energy. It is in line with the booming development of the hydropower industry and clean production requirements.  

2.4.6 Driving forces of the changes of crude oil-related water consumption  

Fig. 7. Driving factors for crude oil-related water consumption change.  

Table. 6. Contributions of driving forces of the changes of crude oil-related water consumption($10^6$m$^3$).  

As shown in Fig.7 and Table.6, for water consumption change in crude oil production process, the economic activity and population were still the promoting factors changing water consumption from 2012 to 2015. Meanwhile, the change trend of water consumption intensity and industrial structure of crude oil production process were similar with it of hydropower and natural gas production process.  

2.5 Conclusions  

This research illustrates that population effect and economic activity effect were dominant effects driving water consumption changes, while the improvement of consumption intensity and structure were main inhibiting factor on water consumption growth. Population played as main driver for water consumption change for all kinds of energy. With China’s second-child policy, this factor would continue to positively affect resource consumption in the coming decades. However, the influence of population increases on water consumption tends to be minor. The affluence effect also played as a promoting effect and always as the major influencing factor, which indicates that China’s economic development is in a good shape. But its impact is constantly decreasing, which shows that our economy is shifting from resource-intensive towards resource-efficient mode.
The industrial structure effect of natural gas and hydropower showed different or even opposite effect from it of raw coal and thermal power. This reflects the fast development trend of cleaner production in the current society. Environment friendly culture in society should therefore be promoted to make the consumers voluntarily choose clean energy as alternative sources, such as natural gas and hydropower.

### 2.6 Tables

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### 2.7 Figures

[Figure 1](#) The changes of total energy production-related water consumption.
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Fig. 3. Driving factors for raw coal-related water consumption change.

Fig. 4. Driving factors for thermal power-related water consumption change.

Fig. 5. Driving factors for hydropower-related water consumption change.

Fig. 6. Driving factors for natural gas-related water consumption change.

Fig. 7. Driving factors for crude oil-related water consumption change.

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Reference

