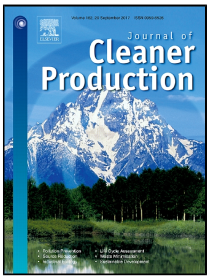

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Relationship between Energy Production and Water Resource Utilization: A Panel Data Analysis of 31 Provinces in China

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Abstract: The systematic study of the relationship between energy production and water resource utilization is crucial for China to relieve the energy-water crisis and achieve sustainable use of them. This work explores the causal relationship between energy production and water resource utilization in China, using panel data of 31 provinces over the period 2000-2014. This study have applied a panel unit root test, cointegration test, vector error correction model (VECM) and Granger causality approaches to examine the long-run and short-run relationship between the variables. The results show that: (1) There is a long-run bidirectional Granger causality relationship between energy production and water resources utilization, but a short-run unidirectional relationship between two variables, i.e. the water resource utilization is the short-run Granger reason for the change in energy production; (2) the increases in industrial added value, population and ratio of the secondary industry value added to GDP have a positive effect on both energy production and water resource utilization; (3) industrial water use will fall by about 0.12% if the rate of industrial waste-water reuse increases by 1%, which shows that the progress of water-saving technology can reduce industrial water usage effectively. Our findings indicate that government should implement strict water constraint strategies and promote water conservation technology for the sustainable development of energy and water resources in China.

Keywords: Energy Production; Water Resource Utilization; Energy-water nexus; Granger Causality; Panel Data; China

1. Introduction

Energy and water are important resources to support economic and social development. There is a significant interdependence between them in industrial economies. On the one hand, water resources (such as cooling water) are needed for energy extraction, processing and conversion. And the development of renewable energy such as biofuel cultivation may result in a rapid increment for water consumption. On the other hand, a reliance on energy input also exists in the whole life cycle of water exploitation and utilization. With the development of the global economy, the demand for the two sorts of resources is extensive. It is of significance to analyze the relationship between the two sectors to realize their sustainable utilization.

For developing countries with large populations, the realization of the relationship between energy and water resources is the basis of sustainable development. As the world's largest developing country, China's urbanization and industrialization processes have contributed to a rapid increase in energy demand. In order to meet the domestic energy demand, the energy production in China increased from 6.37 tons of standard coal equivalent (tce) in 1980 to 36.19 tce in 2014 (National Bureau of Statistics PRC, 2016). Energy production cannot be separated from the use of water resources. With the growth of China's energy production and consumption, the demand for water resources will inevitably increase. Compared with 2010, China's water consumption caused by energy

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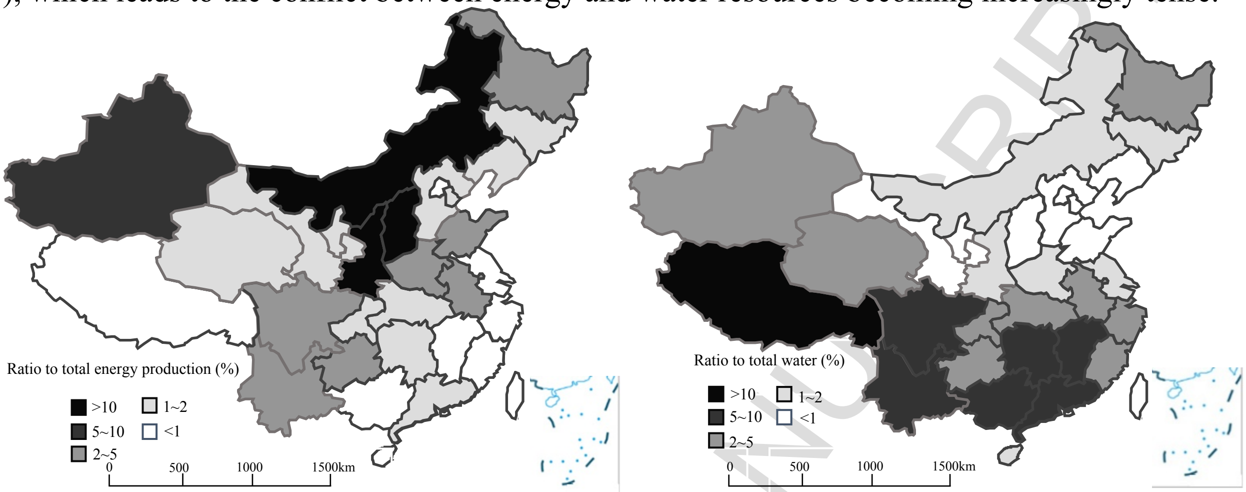
production is projected to grow by 83% in 2035 under the new policy scenario[1], mainly originating from thermal power production and consumption (International Energy Agency, 2012).

China is rich in water resources, with 281.3 billion cubic meters, accounting for 6.57% of the global total in 2014 (Asian Development Bank, 2016). However, per capita water ownership is just 2061.91 cubic meters, comprising only 1/3 of the world average in 2014 (National Bureau of Statistics PRC, 2016).Therefore, China is facing a serious water shortage problem. In particular, there are significant regional differences in water resource endowment in China, with more in south and less in north. This creates a characteristic of reverse distribution of energy endowment in China (Figure 1), which leads to the conflict between energy and water resources becoming increasingly tense.



a. Energy production classification b. Water resources classification

Fig.1. Energy production and water resources of 31 provinces in 2014

Source: National Bureau of Statistics PRC (2016)

Furthermore, the growth of energy demand and measures to address the shortage of water resources may exacerbate this conflict. On the one hand, the shortage of water resources has become one of the main factors restricting the development of energy. For example in Shanxi, Shaanxi and Inner Mongolia provinces, the energy production accounted for 50.94% of total production in 2014 (Figure 1a), but the amount of water resources in the three provinces was only 3.67% of the country's total (Figure 1b) (National Bureau of Statistics PRC,2016). Since energy production needs water, a water shortage, uneven distribution of water resources, or lack of groundwater will limit energy development in dry areas, which is not conducive to the supply of energy in the future. On the other hand, in order to alleviate the pressure of water resources, China has been developing some large water engineering projects, such as South-to-North Water Diversion and Desalination which need a large amount of energy as power input, aggravating the energy-water crisis. This vicious circle is deleterious to the sustainable development of China. Therefore, it is an urgent necessity to study the relationship between energy production and water resource utilization in China. In China's policy planning, great attention has been paid to saving water and improving energy efficiency. For saving water, the 11th Five-Year (2006-2010) and 12th Five-Year plans (2011-2015) set the objective that water consumption of per unit industrial added value should decrease by 30%. The 13th Five-Year plan (2016-2020) sets the objective that water consumption of per unit GDP should decrease by 23%. For saving energy, the 13th Five-Year plan sets the objective that energy consumption of per unit GDP should decrease by 15% from 2015 to 2020. However, the energy and water resource management of China have belonged to different departments for a long time, and policy makers tend to neglect the relationship between energy production and water resource utilization in terms of the development and utilization of energy and water resources. Gu et al. (2016) pointed out that in the

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[1] The new policy scenario: it is an influence evaluation scenario that broadly considers various countries' policy commitments and their upcoming climate policies.

process of formulating the national macro energy policy, decision-makers do not consider its impact on water resources, and there is no consideration of the impact on energy consumption and greenhouse gas emissions in the process of formulating water policy. Therefore, it would be helpful for Chinese energy-water policy making to have a better understanding of the relationship between energy and water in China.

Based on this consideration, this study uses quantitative econometric methods to study energy and water interdependence from the perspective of economic and social development. In accordance with the availability of data, the work focus on the causal relationship between energy production and water resources utilization, applying panel data of 31 provinces in China over the period 2000-2014. Compared with time series or cross-sectional data analysis, panel data analysis can potentially make the estimated results more accurate because it can solve the problem of the so-called omitted variable, known as the endogenous problem (Wooldridge, 2009). In detail, a correlation model of regional energy production and water resources in China has been developed in this study to quantify the interdependence between them, by using a panel unit root test, cointegration test, and vector error correction model (VECM) and Granger causality analysis. Moreover, in order to analyze the impact of economic and technological factors on energy production and water resource use, mixed regression model, individual fixed effects regression model and individual random effects regression model are applied in the paper. Based on these quantitative results, some policy implications are put forward in this work, which are significant for the sustainable development of energy and water resources of China in the future.

2. Literature review

Overall, the research of the energy and water nexus is still at a relatively preliminary stage, and can be roughly divided into two aspects, the water consumption of the energy sector and the energy consumption of the water sector. Most of the studies on the water consumption of the energy sector were carried out from the viewpoint of technology. They were mainly concerned with the actual water consumption of different types of energy technology, including fossil energy (coal, oil and natural gas) (Clark et al., 2013), wind energy (Yang and Chen, 2016), solar energy (U.S. Department of Energy, 2010), other clean energy (Pacetti et al., 2015) and electrical energy (Bijl et al., 2016; International Energy Agency,2016), and the impact of the energy process on the hydrological environment (Denooyer et al., 2016).

In addition, some scholars have focused on analyzing the water resource demand of energy sectors in a certain region from the perspective of the whole industry, and comparing it with the carrying capacity of the local water resources (Ackerman and Fisher, 2013; Fang and Chen, 2016; Spang et al., 2014). For example, Spang et al. (2014) calculated the water consumption caused by energy production of different energy portfolios of 158 countries in the world. Some other scholars have predicted the energy demand under the constraint of water resources. For instance, Ackerman and Fisher (2013) estimated the supply and demand of electricity in the western United States under four scenarios, such as carbon emission reduction scenarios and water saving scenarios, from the point of view of water supply in electricity generation.

Regarding the studies on the relationship between water and energy in China, most of them have concerned coal mining, which is closely related to the specific energy structure of China. For instance, Shang et al.(2016) analyzed the situation of water supply and water consumption of 14 large coal bases in China in 2020; According to a series of problems of coal resources and water resources allocation, Yang et al. (2015) put forward corresponding measures for the coordinated development of regional ecology, economy and environment in order to realize the balance of coal production and consumption in the region of China.

At present, there is far less research on the energy consumption of the water sector than on the water consumption of the energy sector. This is mainly because the restraint on energy caused by a shortage of water resources is arguably a more severe problem for global sustainable development.

Nevertheless, many scholars have studied the energy consumption of the water sector from the point of view of energy intensity (Gunson et al., 2010; Plappally and Lienhard V, 2012). They analyzed energy consumption per unit water in the whole processes of the water sector, including exploitation (Plappally and Lienhard V, 2012), transportation (International Energy Agency, 2016), use (Griffithssattenspiel and Wilson, 2009), and treatment (Lam et al., 2017). For example, Griffithssattenspiel and Wilson (2009) found that the energy consumption of household water heating was 148,017~159,215kWh/MG, while the energy consumption of transportation was about 6,260kWh/MG. Moreover, some scholars have also focused on hydropower, hydrogen production from water, which could be regarded as the use of water resources for the energy sector (Mattmann et al., 2016; Mao et al., 2016; Zhang and Xu, 2015; Kwak et al., 2014; Ozbilen et al., 2012). For example, through the development of an econometric model, Mattmann et al. (2016) evaluated the economic benefits of hydropower. Mao et al.(2016) presented a theoretical analysis of hydropower generators in a comprehensive manner via the Theory of Inventive Problem Solving and life cycle assessment methods.

In terms of the research methods, the existing research methods of the energy and water nexus can be divided into three categories. First, the life cycle method (Fang and Chen, 2016; Stokes and Horvath, 2009) and the input-output method (Aviso et al., 2011; Wang and Chen, 2016; Zhang and Anadon, 2014) are usually used to calculate the quantitative interaction between the two departments. Second, the price elasticity method is used to study the relationship between water price and water-energy nexus (Marsh, 2008). Third, scenario analysis is always used to simulate the possible relationship between energy and water resources in different conditions of economic development (Ackerman and Fisher, 2013; Shang et al., 2016; Wood and Alsayegh, 2014).

In summary, although the existing studies focus on the energy production and water consumption in the context of energy-water nexus, most of them are concerned with saving water in a specific energy production process, or analyze the static relationship between energy and water resources in a certain area, department or industry. There is still a lack of literatures about the interdependence of energy and water resources from the perspective of a whole region or country. To narrow the research gap left by previous studies as well as make contributions for policymakers to make future energy and water resource strategy in China, the present study make a comprehensive analysis to understand the macro-coupling relationship between energy and water resources in China. This work is the first attempt to establish an econometric model to analyze the water energy coupling relationship with the use of panel data of 31 provinces over the period 2000-2014, which can obtain a quantitative and concrete result. In addition, macroeconomic variables such as industrial value added (IVA) are added to the models in this study creatively, which makes the results more reliable.

3. Econometric model and data source

3.1. Energy and water variables

3.1.1 Energy Production

As the basis for the development of other industries, the power sector plays a key role in economic and social development. The total electricity consumption in China has increased from 1.36 trillion kWh in 2000 to 5.55 trillion kWh in 2015 (National Bureau of Statistics PRC, 2016), with an average annual growth rate of 10.29%. At the same time, the electricity generation sector is the largest water consumer and water withdrawer in the whole energy system (International Energy Agency, 2012), which makes it reasonable to choose the electricity production to interpret energy production when analyzing the related water issues. In China, the water used in electricity sector is also dominating in the water used in energy sector, which is accounting for 60.8% in terms of water consumption while 89.72% in terms of water withdraw in 2007 (Zhang and Anadon, 2014). Therefore, this paper takes electricity production as the representative to study the relationship between energy production and water use.

3.1.2 Water Use

So far, since the data on the water consumption of energy production or electricity generation in China is not available, industrial water consumption was used as a proxy variable to represent the water use. The main consideration for this choice is that using industrial water consumption as the water use variable can, to a large extent, reflect the relationship between energy production and water resource utilization since there is a close linkage between the industrial sector and the energy industry.

3.2. Other related factors

In addition to the interaction between the two variables themselves, energy production and water consumption are also affected by many other factors, including economic development, population growth, urbanization, industrialization, technological progress, climate change, policy adjustments, etc. Based on the availability of data and in order to avoid the problem of multicollinearity[2]. This paper focus on the effects of four main factors, including economy, population, technology and industrial structure.

3.2.1 Industrial Value Added (at 2000 constant prices)

Energy and water resources are the necessary factor inputs for industrial production, so these resource inputs may be closely linked with industrial value added or economic growth. On the one hand, many studies have pointed out that economic growth has an impact on energy consumption and energy production (Huang et al., 2008; Zhang and Cheng, 2009). On the other hand, some studies have indicated that there is an inverted "U" relationship between industrial added value and industrial water consumption (Zou and Liu , 2015). In addition, Chen and Chen (2016) also demonstrated that economic growth has an important influence on the relationship between energy and water resources. Therefore, the industrial value added variable is included in the econometric model in this paper, which is converted at 2000 constant prices.

3.2.2 Population

Population growth has an impact on demand of energy and water, further affecting the development of energy and water resources. In order to avoid the problem of multicollinearity, the non-agricultural population is used as the proxy variable of population index.

3.2.3 Ratio of the secondary industry value added to GDP

China has been energetically developing industry and the construction industry in particular, since Reform and Opening-up, and the ratio of the secondary industry value added to GDP has been maintained more than 40% (National Bureau of Statistics PRC,2016). Many studies have pointed out that the demand for energy in the secondary industry is significantly higher than that in other industries (Khan et al., 2015; Zhang and Cheng, 2009). Therefore, different industrial structures will lead to different energy demands. The ratio of the secondary industry value added to GDP is selected as an influential factor in energy production model.

For water-use, because three out of the top ten major water-use sectors are in secondary industry, including Mining and Washing of Coal, Processing of Petroleum and Coking, Production and Supply of Electric Power and Heat Power. The water consumption in the three sectors was about 12.7% of total water consumption in 2007 (Zhang and Anadon, 2014). If the ratio of the secondary industry value added increases, the water consumption is also expected to increase. Therefore, the ratio of the secondary industry value added to GDP is regarded as an influential factor in water resources utilization model.

3.2.4 Water-saving Technology

Water-saving technology plays an important role in the water use of energy production. Ackerman and Fisher (2013) pointed out that some water-saving technologies can significantly reduce the use of water resources. Tang and Qu (2015) illustrated that we need to continuously improve the level of water saving technology in China and regard water utilization efficiency as an

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[2] The multicollinearity is a linear relationship between explanatory variables, resulting spurious regression.

important management index of energy industry. As a consequence, the paper adds water-saving technology to the water use model. Following Zou and Liu (2015), the rate of industrial waste-water-reuse is used as the proxy variable of the water-saving technology. It can be predicted that in the case of the other factors remaining unchanged, industrial water consumption will decline if water-saving technology advances.

3.2.4 Data source

The data on the electricity production, industrial water use, industrial value added, ratio of the secondary industry value added and non-agricultural population are from the China Statistical Yearbook (National Bureau of Statistics PRC, 2000–2015a). Meanwhile, because the China Statistical Yearbook began to issue the industrial water consumption data of provincial regions in 2002, as a result, the annual industrial water consumption data from 2000 to 2002 is collected from the Water Resources Bulletin (2001-2002) (Ministry of Water Resources, 2001; Ministry of Water Resources, 2002) and authors' arrangement. And the data of the rate of industrial waste-water reuse is from the China Environmental Statistical Yearbook (National Bureau of Statistics PRC, 2000–2015b).

The descriptive statistics of all variables used in this paper are in Table 1.

Table 1
Descriptive statistics of all variables

Definition	Unit	Mean	Median	Max	Min	Std.dev
EP(Electricity production)	10^9 kWh	1060.43	775.53	4347.57	6.61	889.59
WU (Industrial water use)	10^9 m^3	42.78	26.79	237.97	0.34	42.35
IVA(Industrial value added)	10^9 yuan	4496.99	2683.47	29144.15	10.17	5211.61
WST(Rate of industrial waste-water-reuse)	%	77.99	84.88	96.48	0.15	18.55
SR(Ratio of the secondary industry value added)	%	46.05	47.60	61.50	19.80	8.33
P(Non-agricultural population)	10000	1365.14	1161.16	4827.43	35.29	965.48

3.3 Estimation methods

3.3.1. Panel unit root test

In order to avoid spurious regression problems, the non-stationarity variables can not be used directly in the regression model. Therefore, it is necessary to carry out a unit root test of panel data before estimating the relationship between energy production and water resource utilization. There are various methods to conduct a panel data unit root test. In order to avoid test errors caused by the limitations of the method and to ensure accuracy, the LLC test (Levin et al., 2002), IPS test (Im et al., 2003), ADF-F test (Maddala and Wu, 1999) and PP- F test (Maddala and Wu, 1999) are used to test the stationarity properties for each variable in this study.

3.3.2. The panel cointegration test

The panel cointegration test is used to study the long-run stationarity relationship among energy production, water use and other influencing factors. Considering the small sample properties of the data, following Pedroni (1999), this paper not only considers the Panel ADF test and the Group ADF test to identify the existence of co-integration relationship between variables, but also refers to the Panel PP test and Group PP test. In addition, the Kao test (Kao, 1999) and the Johansen Fisher test (Johansen, 1988) are also considered in this paper, combining the three test results to test the cointegration relationship.

3.3.3. Fixed effects model (FEM)

After the cointegration test, if all the variables are cointegrated, the impact of explanatory variable on the dependence variable can be estimated. Because our panel data of 31 provinces of China are from 2000 to 2014, while the time dimension (T period) is smaller than the cross- sectional dimensions (n individuals), it is appropriate to use the fixed effects regression model rather than the random effects model. In addition, the time difference of water use and energy production is not obvious, so the main model of this paper is the individual fixed effects model rather than the time fixed effects model. In order to ensure the reliability of the model, in addition to the establishment of individual fixed effects model, mixed model and individual random effects model are established in this paper, and test whether the selection of the individual fixed effects regression model is reliable or not by the following assumptions.

1) According to the results of the likelihood ratio (LR) test (Larsson et al., 2001) and the Hausman test (Hausman, 1984), using EVIEWS8.0, it can determine whether to apply the individual fixed effects model or the individual random effects model.

2) Whether choosing an individual fixed effects model or a mixed model requires a hypothesis test:

H_0 : The intercepts of different individuals are the same (real model is panel mixed model).

H_1: The intercepts of different individuals are different (real model is individual fixed effects model).

Statistic F is defined as Eq. (1) ：

$$F = \frac{(SSE_r - SSE_u) / [(NT - K_1 - 1) - (NT - N - K_2)]}{SSE_u / (NT - N - K_2)} \tag{1}$$

Where SSE_r is the sum of squares of residuals of the panel mixed model. SSE_u is the sum of squares of residuals of the individual fixed effects model. K_1, K_2 are the number of explanatory variables of the mixed model and the individual fixed effects model, respectively. N is the number of cross sections, T is the number of years.

Suppose α is the significance level. If $F_\alpha \leq F_{(NT-K_1-1,\ NT-N-K_2)}$, it means accepting H_0 and it should select the mixed model. If $F_\alpha > F_{(NT-K_1-1,\ NT-N-K_2)}$, it means refusing H_0 and it should select the individual fixed effects model.

In order to eliminate the heteroscedasticity and volatility that may exist in the variables, and to reflect the long-term elastic relationship between energy production and water use, logarithmic variables are used in this paper. The natural logarithm of all variables is named by $lnEP$, $lnWU$, $lnIVA$, $lnSR$, $lnWST$ and lnP . Therefore, based on the data availability and the actual situation of China, the relationship between energy production and water resource utilization is modeled in Eq.(2) and Eq.(3).

$$lnEP_{it} = c + a_i + \beta lnWU_{it} + \gamma lnZ_{it} + \varepsilon_{it} \tag{2}$$

$$lnWU_{it} = c + b_i + \lambda lnEP_{it} + \delta \ln U_{it} + \varepsilon_{it} \tag{3}$$

Where EP_{it} is electric power production; WU_{it} is industrial water consumption； i means the province , t is the year, and Z_{it} denotes other factors affecting energy production (part or all of the industrial value added, ratio of the secondary industry value added and population). U_{it} denotes other factors affecting water resources utilization (part or all of the industrial value added, ratio of the secondary industry value added, reuse rate of industrial waste water and population). a_i and b_i represent the fixed effects in region i, reflecting the individual differences of region in the model. β、γ 、λ δ are the coefficients of explanatory variables. ε_{it} is the random error term in the model.

3.3.4. Vector error correction model (VECM)

Through cointegration analysis and panel fixed effects regression model estimation, the long-run stationary relationship between energy production, water use and their other influencing factors is usually a type of non-equilibrium process. Thus, in order to further analyze the short-run relationship between energy production and water resource utilization, following Pesaran et al. (1999), the vector error correction model (VECM) is used in this study, which is prepared for the panel Granger causality test. The vector error correction model is as follows:

$$\Delta ln(EP)_{it} = c + \sum_{j=1}^{k} \beta_{11j} \Delta lnWU_{i(t-j)} + \sum_{j=1}^{k} \beta_{12j} \Delta lnIVA_{i(t-j)} + \sum_{j=1}^{k} \beta_{13j} \Delta lnSR_{i(t-j)} + \sum_{j=1}^{k} \beta_{14j} \Delta lnP_{i(t-j)} + \sum_{j=1}^{k} \beta_{15j} \Delta lnEP_{i(t-j)} + \lambda_1 ECM_{i(t-1)} + \varepsilon_{it} \quad (4)$$

$$\Delta ln(WU)_{it} = c + \sum_{j=1}^{k} \beta_{21j} \Delta lnEP_{i(t-j)} + \sum_{j=1}^{k} \beta_{22j} \Delta lnIVA_{i(t-j)} + \sum_{j=1}^{k} \beta_{23j} \Delta lnSR_{i(t-j)} + \sum_{j=1}^{k} \beta_{24j} \Delta lnWST_{i(t-j)} + \sum_{j=1}^{k} \beta_{25j} \Delta lnP_{i(t-j)} + \sum_{j=1}^{k} \beta_{26j} \Delta lnWU_{i(t-j)} + \lambda_2 ECM_{i(t-1)} + \varepsilon_{it} \quad (5)$$

In the above models, $\Delta lnEP$, $\Delta lnWU$, $\Delta lnIVA$, $\Delta lnSR$, $\Delta lnWST$ and ΔlnP are the first differences of these variables, representing the short-run variation of the six variables, j is the number of lag order, ECM is residual, λ is the coefficient of correction, which represents the speed of adjustment from non-equilibrium to long-term equilibrium. β is the estimation coefficients of explanatory variables, representing short-run impacts on the dependent variable.

3.3.5. Granger causality analysis

Following Granger (1980), there is at least one direction of Granger causality if a cointegration relationship exists between two non-stationary time variables. It also applies to panel data. If the correlation coefficient between two variables is statistically significant, it can be concluded that there is a causal relationship between the two variables. According to the results of the error correction model, it can carry out the causality analysis. Referring to Nasreen and Anwar (2014), in the above VECM models, ECM is one period lagged error term used to identify the long-run Granger causality between the variables. The short-run Granger causality between the variables is tested by hypothesis test as follows:

The null hypothesis is $H_0 : \beta_{11j} = 0 (j = 1, 2.....k$, *WU* is not the cause of *EP* in the short-run.

The null hypothesis is $H_0 : \beta_{12j} = 0 (j = 1, 2.....k$, *EP* is not the cause of *WU* in the short-run

Long-run dynamics can be tested using t-tests. Short-run dynamics can be tested using Granger Causality F-tests.

4. Empirical results and discussion

4.1. Panel unit root test results

Table 2 presents the estimated results of unit root test, including the LLC test, IPS test, ADF-F test and PP- F test. Due to the LLC test request data being homogeneous (Im et al., 2003), this paper thus mainly refers to the IPS test, ADF-F test and PP-F test. The results of the three tests show that all the variables are non-stationary in their level form, but they are stationary at first difference, rejecting the null hypothesis of a non-stationary series at 1% level of significance. In the other words, the unit root test results show that all series are integrated of order one (I(1)), which is consistent with the general characteristics of most macroeconomic variables. Therefore, it is appropriate to carry out a cointegration test using these variables.

Table 2

Results of panel unit root test

Variable names	*EP*		*WU*		*IVA*	
	level	first difference	level	first difference	level	first difference
LLC test	-2.132**	-15.754***	-2.104**	-14.205***	5.218	-10.888***
	(0.017)	(0.000)	(0.018)	(0.000)	(1.000)	(0.000) ***
IPS test	1.207	-10.083***	0.268	-10.393***	6.013	-3.617***
	(0.886)	(0.000)	(0.606)	(0.000)	(1.000)	(0.000)
ADF-F test	60.493	209.949***	53.968	227.072***	26.501	102.726***
	(0.531)	(0.000)	(0.756)	(0.000)	(1.000)	(0.001)
PP-F test	56.090	313.053***	45.107	257.513***	21.788	157.832***
	(0.687)	(0.000)	(0.947)	(0.000)	(1.000)	(0.000)

Variable names	*WST*		*SR*		*P*	
	level	first difference	Level	first difference	level	first difference
LLC test	-4.827***	-10.593***	-0.893	-17.450***	-0.108	-33.664***
	(0.000)	(0.000)	（0.186）	(0.000)	(0.457)	(0.000)
IPS test	-0.503	-8.265***	-0.053	-14.896***	4.397	-11.585***
	(0.307)	(0.000)	（0.479）	(0.000)	（1.000）	(0.000)
ADF-F test	68.056	185.784***	67.360	291.946***	33.891	166.555***
	(0.279)	(0.000)	（0.299）	(0.000)	（0.999）	(0.000)
PP- F test	64.754	197.562***	90.092	354.397***	22.936	238.674***
	(0.381)	(0.000)	（0.598）	(0.000)	（1.000）	(0.000)

Note: ( ) is the p value, * indicates significance at 10% level, * *indicates significance at 5% level, *** indicates significance at 1% level. The specifications contain intercept and the trend variables in *EP*, *IVA* and *P*, while the specifications only contain intercept without the trend in others. The maximum lags are selected according to Akaike information criterion (AIC) (Wooldridge, 2010).

4.2. Panel cointegration results

Table 3 shows the results of the overall cointegration test between *Electricity production* and other variables. Table 4 shows the results of the overall cointegration test between *Industrial water use* and other variables. In the overall cointegration test model (the last column of Table 3 and Table 4), the results of the Panel ADF test, Panel PP test, Group ADF test and Group PP test reject the null hypothesis at 1% level of significance. Kao-ADF test also gives this result. This indicates that there is a long-run cointegration relationship among all variables. In order to understand the degree of influence among variables, regression analysis is needed.

Table 3

Cointegration test results of *lnEP*

Test method		*lnWU*	*lnIVA*	*lnSR*	*lnP*	*ALL*
Pedroni test	Panel-v test	40.100***	-0.381	42.315***	19.130***	-1.948
		（0.000）	（0.648）	（0.000）	（0.000）	（0.974）
	Panel-rho test	1.222	0.826	0.333	0.118	2.722
		（0.889）	（0.796）	（0.631）	（0.547）	（0.997）
	Panel-PP test	-2.140**	-3.918***	-5.229***	-5.806***	-9.674***
		（0.016）	（0.000）	（0.000）	（0.008）	（0.000）
	Panel-ADF test	-3.585***	-6.972***	-8.061***	-8.445***	-7.275***
		（0.000）	（0.000）	（0.000）	（0.000）	（0.000）
	Group-rho test	2.892	2.195	2.196	2.254	5.500
		（0.998）	（0.986）	（0.986）	（0.988）	（1.000）

	Group-PP test	-2.055** （0.020）	-4.532*** （0.000）	-7.021*** （0.000）	-8.779** （0.000）	-15.357*** （0.000）
	Group-ADF test	-3.008*** （0.001）	-6.786*** （0.000）	-7.104*** （0.000）	-8.897*** （0.000）	-9.822*** （0.000）
Kao test	ADF	-2.408*** （0.008）	-3.438*** （0.000）	3.086*** （0.001）	-2.307** （0.011）	-3.839*** （0.000）
Johansen Fisher test	None	182.4*** （0.000）	149.5*** （0.000）	155.2*** （0.000）	269.1*** （0.000）	-- --
	At most 1	131.6*** （0.000）	145.7 （0.928）	85.48** （0.026）	96.31*** （0.003）	-- --

Note: ( ) is the probability value, * indicates significance at 10% level, * *indicates significance at 5% level, *** indicates significance at 1% level. The specification contains intercept without the trend. The maximum lags are selected according to Akaike information criterion (AIC) (Wooldridge, 2010).

Table 4

Cointegration test results of *lnWU*

Test method		*lnEP*	*lnIVA*	*lnSR*	*lnWST*	*lnP*	*ALL*
Pedroni test	Panel-v test	3.184*** (0.001)	2.544*** (0.006)	1.677** (0.047)	0.340 (0.367)	3.116*** (0.001)	-1.358 (0.913)
	Panel-rho test	-0.920 (0.179)	-1.501* (0.067)	-1.457* (0.073)	-1.834** (0.033)	-1.597* (0.055)	3.876 (1.000)
	Panel-PP test	-1.826** (0.034)	-1.949** (0.026)	-2.629*** (0.004)	-4.290*** (0.000)	-2.435*** (0.007)	-2.627*** (0.004)
	Panel-ADF test	-2.917** (0.002)	-3.118*** (0.001)	-3.479*** (0.000)	-1.089 (0.138)	-3.655*** (0.000)	-3.427*** (0.000)
	Group-rho test	0.255 (0.601)	0.383 (0.649)	0.987 (0.838)	0.503 (0.692)	0.443 (0.671)	6.412 (1.000)
	Group-PP test	-2.017** (0.022)	-1.502* (0.067)	-1.520* (0.064)	-2.492*** (0.006)	-1.691** (0.045)	-7.888*** (0.000)
	Group-ADF test	-4.851*** (0.000)	-3.768 *** (0.000)	-4.818*** (0.000)	-3.094*** (0.001)	-3.419*** (0.000)	-7.014*** (0.000)
Kao test	ADF	-2.027** (0.021)	-1.685** （0.046）	-2.554*** (0.005)	-1.667** （0.047）	-1.765** （0.038）	-1.948** (0.026)
Johansen Fisher test	None	182.4*** （0.000）	141.7*** （0.000）	181.6*** （0.000）	189.0*** （0.000）	239.5*** (0.000)	-- --
	At most 1	131.6*** （0.009）	157.1*** （0.000）	154.0*** （0.000）	145.5*** （0.000）	156.7*** (0.000)	-- --

Note: ( ) is the p value, * indicates significance at 10% level, * *indicates significance at 5% level, *** indicates significance at 1% level. The specification contains intercept without the trend. The maximum lags are selected according to Akaike information criterion (AIC) (Wooldridge, 2010).

4.3. Influencing factors analysis

In order to estimate the impacts of water use and other factors on energy production, and the impacts of energy production and other factors on water use, a mixed model (MM), an individual fixed effects model (FEM) and an individual random effects model (REM) are established for each group of regressions. In order to avoid endogenous problems, a fully modified ordinary least squares (FMOLS) method is used to estimate the model coefficients, the results of which is unbiased and valid (Pedroni, 2000). The estimated results are shown in Table 5.

Table 5

The estimation results of FMOLS for the two groups of regression models

Model	ENERGY			WATER		
	MM	FEM	REM	MM	FEM	REM
Obs.	432	432	432	432	432	432

Constant	20.441	4.272***	-0.518	-3.240	2.775***	-0.607***
	（0.571）	(4.808)	(-1.121)	(-1.131)	(3.480)	(-1.068)
lnEP	--	--	--	0.123**	0.111**	0.263***
	--	--	--	(2.175)	(2.011)	(5.008)
lnWU	0.094**	0.072**	0.131***	--	--	--
	(2.302)	(1.667)	(3.924)	--	--	--
lnIVA	0.259***	0.360***	0.584***	0.374***	0.077***	0.127***
	(3.282)	(4.823)	(36.404)	(4.261)	(1.706)	(3.512)
lnSR	-0.127	0.174**	0.114**	-0.085	0.410***	0.754***
	(-0.810)	(1.149)	(1.319)	(-0.485)	(3.179)	(7.785)
lnWST	--	--	--	-0.033***	-0.120***	-0.121***
	--	--	--	(-2.655)	(-2.861)	(-6.103)
lnP	0.121	0.074***	0.373***	-0.272***	0.379***	0.049**
	(0.170)	(2.595)	(6.161)	(-2.626)	(3.772)	(0.625)
AR(1)	0.997***	0.919***	--	0.990***	0.744***	--
	（142.604）	（41.498）	--	(197.639)	(24.037)	--
R-squared	0.793	0.794	0.727	0.783	0.744	0.336
DW	2.167	2.390	0.442	1.904	1.977	0.464
LR test	--	2.092***	--	--	3.640***	--
	--	[0.001]	--	--	[0.000]	--
Hausman test	--	--	39.844***	--	--	87.045***
	--	--	[0.003]	--	--	[0.000]

Note: ( ) is the t value, [ ] is the probability value. * indicates significance at 10% level, * *indicates significance at 5% level, *** indicates significance at 1% level. MM is mixed model; FEM is fixed-effects model; REM is random-effects model.

From Table 5, the results of both the LR test and the Hausman test reject the null hypothesis at 1% level of significance, which means it is better to select the individual fixed effect model. The calculated VIF is about 1.0, which means there is no serious multicollinearity problem and it does not obviously affect estimation results.

When considering the mixed model or the individual fixed effects model, they reject the null hypothesis at 1% level of significance, according to the Eq. (1) and LR test. This means that it should select the individual fixed effects model rather than the mixed model. In addition, the coefficients of *lnSR* in mixed regression model is opposite to those in other two models, which also shows that the mixed effects model may be unreliable. Therefore, individual fixed effects model is adopted as the benchmark for the following discussion.

The coefficients are statistically significantly positive for WU_{it} and EP_{it} in the energy production model and water consumption model respectively. To be specific, water resource use is positively related to energy production at 5% level of significance: as industrial water use increases by 1%, electricity production will increase by about 0.072%. This is because water is usually an essential input for energy production especially in the process of electricity generation. Therefore, the variation of water input would have a positive impact on energy production. Similarly, energy production is also positively related to the water resource use. When electricity production increases by 1%, industrial water use will increase by about 0.111%. This is due to that the power generation needs water resources during the cooling and other processes, the higher energy is produced, the higher water is used. The results prove the existence of an interactive relationship between energy and water in China, which is consistent with our expectation. Moreover, considering the electric production elasticity is relatively high (0.111), the water consumption will increase dramatically in the future due to the huge amount of electricity demand in China (Zhu et al., 2011), which implies that water shortages in China may be more severe.

For the other influential factors of energy production and water use in this study, the effects of ratio of the secondary industry value added to GDP, industrial value added and population in this study are basically consistent with economic theory and experience. Specifically, most coefficients of these control variables are positive at 1% level of significance, indicating that the increase of these factors will improve energy production and/or water consumption, which are consistent with the conclusions of Fang and Chen (2016), Acaravci and Ozturk (2010), Bildirici and Kayıkçı (2013). In addition, it is noteworthy that the coefficient of water-saving technology is negative to water resources use: if the rate of industrial waste-water-reuse increases 1%, industrial water use will fall by about 0.12%, which confirms the effectiveness of water-saving technology.

4.4. Granger causality results

The VECM estimation results are shown in Table 6:

Table 6

Granger causality test based on the VECM

Variables	short-run		Variables	long-run	
	$\Delta lnEP_{it}$	$\Delta lnWU_{it}$		$\Delta lnEP_{it}$	$\Delta lnWU_{it}$
Obs.	400	400	Obs.	400	400
$\Delta lnEP_{it}$	--	0.109*	*ECM*	-0.248***	-0.217***
	--	(0.073)		[-4.660]	[-3.873]
$\Delta lnWU_{it}$	0.097***	--	--	--	--
	(0.002)	--	--	--	--

Note: [ ] is the t value, ( ) is the p value. * indicates significance at 10% level, * *indicates significance at 5% level, *** indicates significance at 1% level.

The coefficients of *ECM* are at the 1% level of significance, indicating that the models adjust well from disequilibrium to long-run equilibrium. This means that the independent variables have a long-run effect on the dependent variables in the two models. It confirms the existence of the long-run Granger causality running from energy production to water resource utilization, and vice versa. Therefore, there is a long-run bidirectional relationship between energy production and water resources utilization. Besides, the coefficient of energy production difference is not significant, reflecting that energy production is not the short-run Granger reason for water resource use. The coefficient of industrial water use difference rejects the null hypothesis at the 5% level, showing the water resource use is the short-run Granger reason for energy production. The results demonstrate that water use has a relatively significant impact on energy production in the short-run term. Therefore, although there is a long-run interaction between energy production and water use, the short-run impact of water resources on energy production is more obvious. This implies strongly to us that it is incorrect to ignore the impact of water resources on the energy system.

5. Conclusions and policy implications

The issues of energy-water nexus has been a research focus in the world but not attracted much attention in China. To meet this research gap, this paper makes an empirical analysis for the relationship between energy production and water resource utilization in China, with the use of panel data of 31 provinces over the period 2000-2014. The panel Granger causality test confirms that there is a long-run bidirectional causal relationship between energy production and water resource utilization. However, there is only a short-run unidirectional causal relationship between energy production and water resources utilization, i.e. water resource utilization is the short-run Granger reason for the energy production changes. And from the investigation of the control variables, this paper also finds that the economic development, population growth as well as the ratio of the secondary industry value added expanding will lead to an increase in water utilized by energy production. Considering the water shortage in China, the water is likely to become a limitation for energy sector development in the future. Therefore, in order to realize the sustainable development of energy and water resources in China, the policy makers should address the key role that water plays when making the energy development strategy and implement some measures such as carrying out strict water constraint strategies. On the other hand, our findings also imply that industrial water use can be reduced effectively through the implementation of water conservation technology. As a consequence, the government should encourage the innovation in water-saving technology such as water cycle utilization and promote its implementation in energy production to ease the water stress for energy sector and realize the sustainable development of energy and water.

6. Limitations and further perspectives

Although this paper has confirmed the existence of the close interrelationship between energy and water in China by using econometric models based on panel data, it is still a preliminary study due to some limitations. For example, since the water use data of energy sectors is not in public in China, industrial water is selected as a proxy variable to represent the water resource utilization. This treatment is fine for a preliminary analysis of energy-water nexus but may be improper when investigating the relationship more accurately and comprehensively. Therefore, more effort will be made in collecting relative data to support a deepen knowledge on these issues. In addition, the characteristic of water use among energy sectors and the specific energy-water nexus relationship in water-deficient region are also important issues which will be addressed in our further research.

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