GREEN EFFICIENCY OF INDUSTRIAL WATER RESOURCE IN CHINA AND ITS INFLUENCING FACTORS: EMPIRICAL EVIDENCE FROM CHINA'S 30 PROVINCES

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(Received 28th May 2019; accepted 21st Jan 2020)

Abstract. Based on the theory of Cobb-Douglas production function, this paper introduces the Socio-Environmental Indicator, industrial blue water footprint and industrial grey water footprint to improve the traditional input-output indicator system, used the Epsilon-Based Measure (EBM) models, to measure green efficiency of industrial water resource (GEIWR) based on provincial panel data from 2004 to 2016 in China, and then applied Tobit model to explore the mechanism. First, the results show that distinct differences in the efficiency from different provinces in China. The efficiency from the eastern regions is higher than that in other regions. Then, some western provinces have a high efficiency with a shortage of water but effective waste water regulation, which indicates that the effective efficiency only symbolizes the region's optimal input-output allocation. In particular, the industrial water-saving potential showed a declining trend but there is still much room for improvement of provinces in central China, such as Hubei, Sichuan and Hunan. Lastly, the environmental regulation, technological progress, regional characteristics, industrial structure, foreign capital utilization and water resource consumption have certain impacts on the efficiency. This paper could be helpful in providing a reference for the evaluation of green efficiency of industrial water resource.

Keywords: *green efficiency of industrial water resource (GEIWR), undesirable output, industrial water footprint, industrial water-saving potential, epsilon-based measure (EBM), Tobit regression model*

Introduction

Water resource is one of the indispensable strategic resource for human survival and economic development. World Commission on Environment and Development (WECD) points out, "Water resource is an important factor that restricts socio-economic development". China is a country lacking in water resource. In addition, the uneven spatial distribution of water resource and water pollution from the extensive economic development have made the water resource to become the bottleneck of the sustainable development of our society and economy. In China's industrial structure, industry plays a leading role in the development of national economy, and industrial water consumption accounts for a large proportion in the total water consumption. Accompanied with the fast development of industrialization in China, the imbalance between water supply and demand and water environmental pollution have constantly challenged the growth quality of China's industrial economy. According to the 2016 Annual Statistic Report on Environment in China, industry is the main industry that consumes water resource and causes the continuous deterioration of water environment. China's industry urgently needs green transformation and takes the road of sustainable development. In particular, the spatial distribution of water resource is extremely uneven in China. Therefore, how to alleviate the contradiction between socio-economic development and resource to improve the efficiency of industrial water resource has become a hot topic among scholars. Water resource is an economic resource that can only generate economic benefits with the help

DOI: http://dx.doi.org/10.15666/aeer/1802_30573072

of other production factors. Therefore, many scholars establish input-output indicator system to measure water resource efficiency. In 2006, Hu et al. (2006) established Data Envelopment Analysis (DEA) model to measure water resource efficiency. Based on this model, many scholars have improved the DEA model and the measurement indicator system. Chen et al. (2018) introduced water resource input into production function from the perspective of input. On this basis, taking the social benefits brought by water resource utilization into the measurement system, Sun et al. (2017) further proposed the concept of green efficiency of water resource, which can fully reflect the coordinated development of society, economy and environment. At the same time, scholars such as You Shaqiu and Ma Hailiang introduced undesirable output indicator into the measurement of green efficiency of water resource, considering the impact of environmental pollution output on water resource efficiency (You, 2017; Ma et al., 2012; Zhang and Liu, 2018). In the selection of DEA model, most scholars choose the traditional radial DEA model, such as Liu et al. (2007), Qian and He (2011) and Chemark et al. (2009). Some scholars choose non-radial SBM (Slack-Based Measure) model (Li and Ma, 2014; Sun et al., 2018; Ding et al., 2018), but both of them have their limitations. In order to comprehensively and objectively apply DEA model, we consider the EBM (Epsilon-Based Measure) model, with both radial and non-radial advantages, which was proposed by Tone and Tsutsui (2010). Once proposed, this model has been widely recognized and applied by scholars, but few studies have applied it to the measurement of green efficiency of industrial water resource (GEIWR).

In summary, scholars have conducted research into the efficiency of industrial water resource, laying the foundation for follow-up development in this field. On the whole, there are still some shortcomings in the current research. (1) The indicators of the efficiency measuring factors must be improved. Currently, there have been many researches on the evaluation and analysis of water resource efficiency from the perspective of economic output, but studies on the environmental and social benefits caused by water resource utilization in the process of economic development are insufficient. Scholars have mainly considered factors such as GDP, labor, capital and water input when studying the efficiency of industrial water resource without considering other factors that reflect socio-economic development (Chen et al., 2018; Li and Ma, 2014; Mai et al., 2014; Zhang et al., 2018; Wang, 2015). The lack of socio-economic development factors fails to reflect the fundamental requirements of the green development concept, will result in an efficiency overestimating or underestimating and deviations from the actual situation. This is not conducive to accurate measure of actual efficiency of industrial water resource and coordinated development of all the country's regions. (2) Most studies only calculated the efficiency and did not further evaluate the water potential regionally. At the same time, some researchers used statistical methods to evaluate the water potential but did not further explore the reasons for the efficiency results. (3) Taking all regions of China as the overall sample will neglect the influence of regional differences caused by various factors of water resource, geographic position and capital input, and lead to errors in the measurement of GEIWR.

Based on thee above understanding, this paper aims to further expand from the following two aspects: (1) Based on the provincial panel data from 2004 to 2016, this paper takes the GEIWR as the research core, chooses China's 30 provinces, cities and autonomous regions as the research object (excluding Tibet, Hong Kong, Macao and Taiwan), uses the EBM model as the main method, introduces SEI (Socio-Environmental Indicator), industrial blue water footprint and industrial gray water footprint to improve indicator system, analyzes the change and trend of the GEIWR in each provincial administrative region of China from the perspective of time and space. (2) In order to provide theoretical guidance for promoting the green transformation of China's industry and realizing the construction of water-saving society in the "13th Five-year plan", this paper estimates the water-saving potential of Chinese provinces, establishes Tobit panel model to explore possible ways to improve the GEIWR. Compared with existing research, the main innovative points of this paper are as follows: (1) It uses EBM to evaluate the GEIWR in China. DEA is a commonly used and effective method for multi-objective decision-making analysis. This paper innovatively applies the EBM method to the study of the GEIWR. At the same time, to eliminate the influence of subjectivity, this paper uses Principal Component Analysis (PCA) to determine the indicator weight of SEI. This method allows it to more objectively reflect the information, rendering the evaluation results more practical. (2) It enriches the indicator system of the efficiency of industrial water resource. In light of the shortcomings of most past studies that do not consider the social benefits of water utilization, this paper adds SEI as desirable output indicators, which can reflect socio-economic development and actual sewage-control situation. Besides, this paper also replaces industrial water utilization by industrial blue water footprint, adds industrial grey water footprint as undesirable output indicators to improve the indicator system. The concept and the indicator system of the GEIWR put forward in this paper better reflect current social development and the water control situation in all provinces, resulting in research results with more practical significance. (3) In the context of this research, we measure industrial water-saving potential by using the measured efficiency. At the same time, this paper also uses panel Tobit model to analyze influencing factors, exploring the underlying causes of the changes in the efficiency.

The structure of this paper as follows: the first section is 'Introduction', the second one, 'Methodology' describes the theoretical mechanism and the research methods, the next sections 'Empirical analysis' and 'Analysis on the influencing factors of GEIWR' demonstrate the results, and the last section provides the conclusion. The second part is the index system and model, the third part is the calculation of efficiency and water-saving potential, the fourth part is the analysis on the influencing mechanism, the fifth part is the conclusions, suggestions and discussions.

Methodology

The indicator system

The DEA approach does not require functional form assumptions between inputs and outputs and can avoid man-made subjectivity in parameter weighting Based on the Cobb-Douglas production function, from the perspective of input and output, this paper established an indicator system for the GEIWR. The indicator system is shown in *Table 1*, and the specific indicators are as follows:

(1) Labor input. The annual average number of employees was used to measure the actual labor input.

(2) Capital input. Referring to the method proposed by Shan Haojie to calculate the capital stock (Shan, 2018), the capital stock of each province is estimated as a measure of the capital input.[1] The perpetual inventory method is used to estimate the capital stock.

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[1] Due to the lack of original data of Chongqing and Sichuan, we estimate the respective capital stock based on the population ratio of the two provinces.

(3) Water resource input. Existing researches showed that the industrial blue water footprint can better reflect the water resource consumption in the process of industrial production, so we used the industrial blue water footprint to measure the input of water resource (Huang et al., 2013).

(4) Desirable output. We took the industrial added value and SEI as the desirable output.

To comprehensively, objectively and scientifically reflect the socio-economic development and the present situation of the pollution control in China, we selected 7 indicators from three aspects of industrial structure, social regulation and technology development.

1) Industrial structure

$$\text{Industrial Structure Proportion}(X1) = \frac{\text{Industrial Added Value}}{\text{Gross Regional Product}};$$

$$\text{Foreign Trade Dependence}(X2) = \frac{\text{Total Value of Imports and Exports}}{\text{Gross Regional Product}}.$$

2) Social regulation

$$\text{Water Resource Restriction}(X3) = \ln(\text{Per Capita Water Resource});$$

$$\text{Population Density}(X4) = \frac{\text{Population}}{\text{Area}};$$

$$\text{Government Waste Water Control}(X5) = \frac{\text{Investment in the Treatment of Industrial Waste Water}}{\text{Industrial Added Value}}.$$

3) Technology development

$$\text{Technical Progress}(X6) = \frac{\text{R\&D Expenditure}}{\text{Industrial Added Value}};$$

$$\text{Technical Market Development}(X7) = \frac{\text{Transaction Value in Technical Market}}{\text{Gross Regional Product}}.$$

Then, to solve the subjective question of the weight assignment, PCA was conducted to obtain the SEI. The weights determined by PCA depends on the characteristics of the data itself, which have strong objectivity and can simplify the statistical data on the premise of preserving the information contained in the original data as much as possible. The results showed that the standardized data passed the KMO-Bartlett test and was suitable for the process of dimension reduction. Through the obtained common factor score and the total variance of each common factor, we can get the factor composite score FAC, and finally the SEI is calculated by using *Equation 1*.

$$\text{SEI}_t = 0.1 + 0.9 * \frac{FAC_t - Min(FAC_t)}{(Max(FAC_t) - Min(FAC_t))} \tag{Eq.1}$$

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_30573072

FAC_t is the factor composite score of the t th province; $Max(FAC_t)$ and $Min(FAC_t)$ are the maximum and minimum value of the corresponding factor composite score respectively.

(5) Undesirable output. The industrial grey water footprint can reflect the pollution degree of the water environment. It refers to the volume of fresh water needed to dilute certain industrial waste water pollutants based on the existing environmental water quality standards. As industrial waste water is directly discharged into water, the discharge amount of main pollutants, Industrial COD (Chemical Oxygen Demand) Emission and Industrial Ammonia Nitrogen, can usually be directly measured as the industrial grey water footprint (Zhang et al., 2017; Hoekstra et al., 2011). In order to consider the constraint effect of industrial water pollution, we take the industrial grey water footprint as the undesirable output part of the output indicator.

Table 1. *Indicator system*

Project	Inputs/outputs	Indicator selection		Measurement and explanations
Input	Labor input	Annual average number of employees		∑[Average number in (January, February, ..., December)] / 12. This input is used to measure the actual labor input
	Capital input	Capital stock		The actual capital stock at the end of year t = the nominal investment in year t / the fixed capital investment price index + (1-the replacement rate) × the actual capital stock at the end of the previous year
	Water resource input	Industrial blue water footprint		Industrial water consumption - industrial sewage discharge. This input can better reflect the water resource consumption in the process of industrial production
Output	Desirable output	Economic output: Industrial added value		This output is the most ideal variable to reflect industrial economic output, and its specific value can be obtained directly in the statistical yearbook of China
		Social output: SEI	Industrial structure proportion	The two rates describe the degree of government emphasis on industry and foreign trade
			Foreign trade dependence	
			Water resource restriction	The three rates describe the level of social regulation from the prospect of water resource, population and sewage treatment
			Population density	
			Government waste water control	
			Technical progress	The two rates indicate the technical level in China
			Technical market development	
	Undesirable output	Environmental output: Industrial grey water footprint		This output reflects the pollution degree of the water environment

Data source

The data are mainly from the "China Environmental Yearbook", "China Statistical Yearbook", "China Water resource Bulletin", "China Industrial Economic Statistical Yearbook" and statistical yearbook of each province from 2004 to 2016. The study object is China's 30 provinces, because the data are from the yearbook statistics, are single-handed information, the reliability and validity of the data have been tested. Moreover, it needs to be noted that the sample includes panel data from 30 provinces in China, in which data in Tibet are missing and removed. In addition, the research range of this paper was selected from 2004 to 2016, mainly for the following reasons: 1) The availability of data. Some of the key variables used in the study do not have complete annual data until 2004, and the data for 2017 has not yet been released completely. 2) It is related to the research topic. Many scholars' similar researches are mainly published during this time. In conclusion, considering the availability of variables' data and the research theme, this paper selects data from 30 provinces in China from 2004 to 2016.

Methods

EBM models

The traditional DEA model can broadly fit into two types. The first classical DEA model is the CCR model, which is established on the basis of constant returns to scale. On the basis of CCR model, BCC model considering variable return on scale assumption can be proposed. But the two basic DEA models, CCR model and BCC model cannot cover slack variables. Other model extensions include slacks-based measure, SBM model. SBM allows all inputs, intermediate variables and outputs to vary in proportion. However, their work cannot guarantee the stage efficiency and efficiency decomposition of the process. In order to solve this problem, EBM, combining radial and non-radial measurement characteristics, was introduced in this paper to measure the GEIWR from 2004 to 2016 in China in order to get closer to the actual efficiency.

For n decision-making units with s input factors (x) and t output factors (y), EBM model can be expressed as follows.

$$\begin{gathered}
\mathrm{X} = \sum_{j=1}^{n} x_{ij} \\
\mathrm{Y} = \sum_{j=1}^{n} \lambda_j y_{rj} \\
\sum_{i=1}^{m} w_i^- = 1 \\
\gamma^* = \min_{\theta,\lambda,t^-} \theta - \varepsilon_x \sum_{i=1}^{s} \frac{w_i^- t_i^-}{x_{i0}} \\
\mathrm{s.t.}\, \theta x_{i0} - \sum_{j=1}^{n} \lambda_j x_{ij} = 0\,, i = 1, \cdots, s \\
\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{r0}\,, r = 1, \cdots, t \\
\lambda_j \geq 0 \\
t_i^- \geq 0
\end{gathered} \tag{Eq.2}$$

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1802_30573072

In the formula, γ^* represents the optimal efficiency value of EBM model considering undesirable output; X is the input value, Y is the output value, X, Y > 0; θ represents the radial efficiency value; t_i^- represents the slack vector of non-radial input elements; λ represents the relative weight value; w_i^- represents the weight value of the i th input variable; ε_x represents key parameters of radial θ and non-radial relaxation t_i^- contained in EBM model (Tone and Tsutsui, 2010).

Tobit model

After calculating the green efficiency of industrial water resources in all provinces and cities of China, this paper will further take the efficiency of industrial green water resources in all provinces and cities as the explanatory variable, and construct econometric model to investigate the influence mechanism of industrial green water resource efficiency in China. Since the range of industrial green water resource efficiency is 0-1, it is a limited dependent variable. If the ordinary least square method is still used, the parameter estimation will be biased and inconsistent. Therefore, Tobit regression model is used in this paper, which is an econometric model for dependent variables of partial continuous distribution and partial discrete distribution. Its specific form is as *Equation 3*.

$$Y_i = \begin{cases} X_i\beta + \mu_i & (\text{When } X_i\beta + \mu_i > 0) \\ 0 & (\text{Others}) \end{cases} \tag{Eq.3}$$

In *Equation 3*, Y_i is the limited dependent variable, X_i is the independent variable vector, β is the parameter vector to be estimated, and the random interference term $\mu_i \sim N(0, \sigma^2), i = 1,2, \ldots$ is the number of observation values. It can be proved that when the Tobit model is estimated by the maximum likelihood method, it can be concluded that $\hat{\beta}$ and $\hat{\sigma}^2$ are consistent estimators.

Empirical analysis

Measurement of GEIWR

Based on the panel data of 30 provinces in China from 2004 to 2016, the green efficiency of China's industrial water resource is calculated by using EBM model in MaxDEA6.0Pro.

The effective GEIWR indicates that its input-output allocation is optimal. As can be seen from *Table 2*, the GEIWR in different provinces showed different development trends from 2004 to 2016. Beijing, Guangdong, Tianjin, Shanghai, Shandong are characterized by having effective DEA value, which indicates that these regions have strong industrial economic strength, optimal allocation of various inputs and outputs in the development process, high level of scientific and technological development and strong ability of comprehensive social development. The GEIWR of these regions is at the optimal level nationwide. The result is consistent with the current situation of China's industrial water resource and social and economic development. In addition, Zhejiang, Chongqing and Fujian have obvious late-mover advantage advantages, and the efficiency value increases gradually from the low initial stage. For example, Zhejiang's efficiency value was only 0.5419 in 2004, but it increased to 0.9240 in 2016.

DOI: http://dx.doi.org/10.15666/aeer/1802_30573072

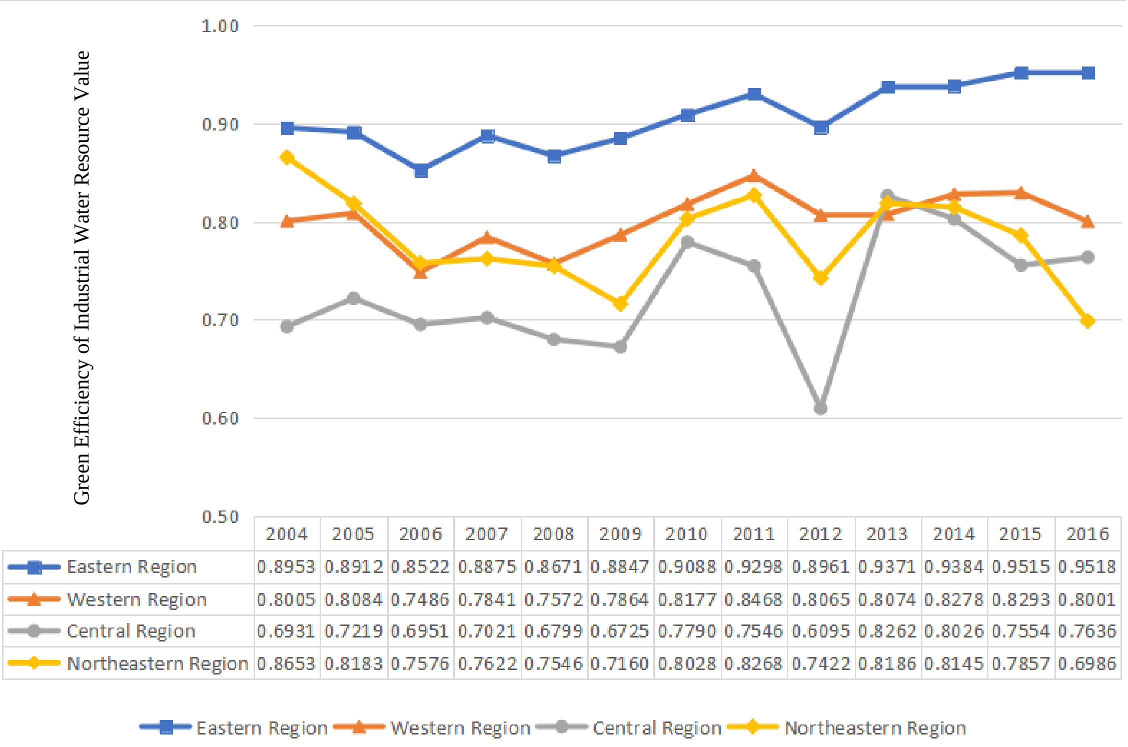
On the contrary, Shanxi and Heilongjiang's efficiency values gradually get below 1.0000, which indicates that in the development process of these regions, the allocation of input and output may be unbalanced. In the western region of Inner Mongolia, Qinghai have high GEIWR. By consulting the input-output data of 2004-2016 and related literature, we found despite each of these areas is lack of water resource and has a low economic development level, but the per capita water resource possession ratio is high, the sewage control has been effective. The result proves that the GEIWR in a region is not necessarily related to the region's economic level.

Table 2. *EBM results of GEIWR*

Region	Province	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Average
Eastern Region	Beijing	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Tianjin	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Hebei	1.0000	1.0000	0.7413	1.0000	0.7171	0.7285	1.0000	1.0000	1.0000	1.0000	1.0000	0.8536	0.9092	0.9192
	Shanghai	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Jiangsu	0.6417	0.6169	0.5958	0.6353	0.6174	0.6619	0.5576	0.6831	0.4994	0.7236	0.6688	0.7454	0.7329	0.6446
	Zhejiang	0.5419	0.5620	0.5103	0.6054	0.6195	0.6777	0.7063	0.7854	0.6732	0.7720	0.7973	0.9165	0.9240	0.6993
	Fujian	0.7694	0.7329	0.6746	0.7287	0.7169	0.7787	0.8243	0.8294	0.7885	0.8750	0.9176	1.0000	0.9515	0.8144
	Shandong	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Guangdong	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	Hainan	1.0000	1.0000	1.0000	0.9054	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9927
Western Region	Gansu	0.7027	1.0000	0.6997	0.6479	0.6406	0.6565	0.8334	0.8657	0.8512	0.7970	0.8571	0.6305	0.6185	0.7539
	Guangxi	0.5711	0.6085	0.4749	0.5471	0.4176	0.6492	0.6099	0.7066	0.5706	0.5891	0.7300	0.8006	0.7889	0.6203
	Guizhou	0.6771	0.7354	0.6836	0.5997	0.6838	0.7641	0.8206	0.7089	0.7231	0.7673	0.8432	0.8372	0.8354	0.7446
	Inner Mongolia	0.8786	0.8826	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9816
	Ningxia	1.0000	1.0000	1.0000	1.0000	0.6453	1.0000	0.6012	1.0000	0.7871	0.5783	0.5877	0.8660	0.6054	0.8208
	Qinghai	1.0000	0.8058	0.7081	1.0000	1.0000	0.8414	1.0000	1.0000	0.9230	1.0000	0.9225	1.0000	1.0000	0.9385
	Shaanxi	0.8612	0.8176	0.7843	0.8122	0.8022	0.7537	0.8527	0.8256	0.9177	1.0000	0.8828	0.8078	0.8370	0.8427
	Sichuan	0.4421	0.4967	0.4596	0.4861	0.5423	0.6167	0.6525	0.6914	0.6253	0.8346	0.8401	0.8107	0.7531	0.6347
	Xinjiang	1.0000	1.0000	1.0000	1.0000	1.0000	0.6626	0.8657	0.8457	0.7855	0.7544	0.7577	0.6813	0.6677	0.8477
	Yunnan	0.7846	0.7555	0.6548	0.7613	0.7622	0.7061	0.7583	0.6712	0.6884	0.5604	0.6849	0.6880	0.6952	0.7055
	Chongqing	0.8877	0.7905	0.7691	0.7704	0.8355	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9272
Central Region	Anhui	0.6329	0.6278	0.6001	0.5907	0.6514	0.7464	0.8376	0.8372	0.7645	1.0000	1.0000	0.8611	0.8786	0.7714
	Henan	0.8592	1.0000	1.0000	1.0000	0.7391	0.5952	0.7546	0.6132	0.3173	0.7142	0.6462	0.6528	0.7313	0.7402
	Hubei	0.4978	0.5588	0.5484	0.5063	0.5657	0.7186	0.7446	0.7826	0.6874	0.8172	0.8173	0.7956	0.8225	0.6818
	Hunan	0.5191	0.5402	0.4990	0.5363	0.5754	0.5763	0.6352	0.6433	0.4686	0.7000	0.7023	0.7230	0.7146	0.6026
	Jiangxi	0.6493	0.6043	0.6465	0.6718	0.6662	0.6890	0.8466	0.7784	0.6692	0.9349	0.9188	0.8700	0.8135	0.7507
	Shanxi	1.0000	1.0000	0.8765	0.9073	0.8815	0.7093	0.8554	0.8730	0.7499	0.7908	0.7310	0.6300	0.6211	0.8174
Northeastern Region	Heilongjiang	1.0000	1.0000	1.0000	1.0000	1.0000	0.7812	0.9525	0.8943	0.7906	0.7633	0.7380	0.6444	0.6208	0.8604
	Jilin	0.8039	0.7670	0.6318	0.6515	0.6177	0.6399	0.6644	0.7261	0.5782	0.8275	0.8252	0.8247	0.8331	0.7224
	Liaoning	0.7920	0.6879	0.6409	0.6351	0.6460	0.7270	0.7915	0.8600	0.8579	0.8651	0.8803	0.8882	0.6419	0.7626
Average		0.8171	0.8197	0.7733	0.8000	0.7781	0.7893	0.8388	0.8540	0.7906	0.8555	0.8583	0.8509	0.8332	0.8199

*Efficiency value of 1.0000 means DEA value is effective

From the average efficiency of all provinces in China, we cannot get obvious data characteristics. Therefore, combined with the common regional classification in China, this paper divides 30 provinces into four regions: the east, the central, the west and the northeast, and analyzes the development trend of their average efficiency. The result clarifies that the change of the GEIWR in different regions of China shows certain regularity. The curves of average efficiency in East, middle, West and Northeast China are shown in *Figure 1*. It can be seen from *Figure 1* that the green efficiency of China's industrial water resource generally presents the law of fluctuation. From 2004 to 2016, except for the eastern region, the changes in the western, central and northeast regions are similar, with the overall efficiency value dropping first till 2006, and then rising, then falling to the lowest level in 2009, and finally rebounding slowly. Combined with China's national conditions in recent years, we find that all these changes show that the three regions especially the central region are greatly affected by different resource and governance policies in different periods. Moreover, the eastern region is always at the leading level of GEIWR in China. Whereas, the GEIWR in the central region is always at the backward level in China, which needs to be improved. This region should be the key area for optimal allocation of water resource.



	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Eastern Region	0.8953	0.8912	0.8522	0.8875	0.8671	0.8847	0.9088	0.9298	0.8961	0.9371	0.9384	0.9515	0.9518
Western Region	0.8005	0.8084	0.7486	0.7841	0.7572	0.7864	0.8177	0.8468	0.8065	0.8074	0.8278	0.8293	0.8001
Central Region	0.6931	0.7219	0.6951	0.7021	0.6799	0.6725	0.7790	0.7546	0.6095	0.8262	0.8026	0.7554	0.7636
Northeastern Region	0.8653	0.8183	0.7576	0.7622	0.7546	0.7160	0.8028	0.8268	0.7422	0.8186	0.8145	0.7857	0.6986

***Figure 1.** The GEIWR values of four regions in China over time*

Assessment of industrial water-saving potential

To sum up, we have analyzed and evaluated China's GEIWR through EBM model. In accordance with the above empirical results, till 2016, the GEIWR in most provinces in China is still less than 1, it proves that the utilization of industrial water resource has not reached the optimal level, and GEIWR can be further improved. We can tap the industrial water-saving potential.[2]

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[2] The connotation of water-saving potential is defined in The Outline of National Water Resource Planning, which refers to the difference between the current water consumption and the water consumption at the optimal level. The industrial water-saving potential studied in this paper is the amount of water-saving stock, which refers to the amount of water-saving that can be achieved by water users under the current situation through water-saving measures to achieve effective utilization of Industrial water resource.

Combined with the meaning of water resource efficiency, the industrial blue water footprint at the optimal industrial water level can be expressed as *Equation 4*.

$$\widetilde{BW_{it}} = BW_{it} \times E_{it} \tag{Eq.4}$$

In the formula, $\widetilde{BW_{it}}$ represents the industrial blue water footprint in the optimal input-output configuration; BW_{it} represents the current industrial blue water footprint; E_{it} represents the GEIWR; i represents the provincial region and t represents the year.

Then, the industrial water-saving potential ΔBW_{it} can be measured as *Equation 5* (Li, 2017).

$$\Delta BW_{it} = BW_{it} - \widetilde{BW_{it}} = (1 - E_{it}) \times BW_{it} \tag{Eq.5}$$

We substituted the GEIWR (E_{it}) calculated by EBM into *Equations 4* and *5*, and the estimated results of China's industrial water-saving potential from 2004 to 2016 are shown in *Table 3*.

***Table 3.** Industrial water-saving potential in China's provinces from 2004 to 2016 (100 million m^3)*

Region	Province	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Eastern Region	Beijing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Tianjin	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Hebei	0.00	3.41	0.00	3.71	3.45	0.00	0.00	0.00	0.00	0.00	1.92	1.13	1.05
	Shanghai	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Jiangsu	68.30	77.45	72.35	70.17	57.12	73.20	53.32	84.84	54.74	72.04	55.59	60.84	65.84
	Zhejiang	17.02	20.94	17.38	15.59	11.28	11.15	9.35	14.10	9.68	8.26	3.08	2.54	12.18
	Fujian	13.46	17.62	16.04	17.40	13.92	12.09	11.22	13.76	8.07	5.36	0.00	2.90	10.99
	Shandong	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Guangdong	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Hainan	0.00	0.00	0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Western Region	Gansu	0.00	4.24	4.38	4.11	3.92	2.03	1.80	1.62	2.25	1.55	3.59	3.50	2.86
	Guangxi	11.93	17.67	13.32	18.13	13.26	15.10	13.84	17.36	19.91	13.37	9.81	9.25	14.27
	Guizhou	7.05	8.20	12.24	10.30	7.74	5.90	8.34	6.28	5.75	3.83	3.68	3.77	7.02
	Inner Mongolia	1.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17
	Ningxia	0.00	0.00	0.00	0.46	0.00	0.77	0.00	0.69	1.45	1.44	0.37	1.12	0.48
	Qinghai	1.07	1.84	0.00	0.00	0.34	0.00	0.00	0.12	0.00	0.12	0.00	0.00	0.27
	Shaanxi	1.56	1.98	1.28	1.59	1.60	1.11	1.59	0.78	0.00	1.22	2.00	1.59	1.35
	Sichuan	22.41	24.84	24.42	21.45	19.55	18.62	17.45	17.87	8.57	6.07	9.13	11.98	17.48
	Xinjiang	0.00	0.00	0.00	0.00	2.58	1.16	1.50	2.02	2.29	2.43	2.86	2.95	1.37
	Yunnan	3.69	5.29	4.49	4.47	5.64	5.41	6.73	7.33	9.28	6.48	5.74	4.99	5.58
	Chongqing	5.13	6.88	7.81	6.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.22
Central Region	Anhui	22.84	29.04	31.30	27.43	21.89	14.12	13.59	21.38	0.00	0.00	11.99	10.56	17.31
	Henan	0.00	0.00	0.00	9.94	15.98	9.94	16.61	31.93	13.24	14.08	13.72	10.26	10.75
	Hubei	32.34	35.14	43.21	38.05	25.80	27.49	23.90	28.84	15.34	14.99	17.42	14.94	27.23
	Hunan	31.38	36.06	33.63	30.91	31.30	29.25	30.63	45.06	25.55	23.66	22.86	23.22	30.33
	Jiangxi	18.13	15.61	16.89	17.71	14.45	7.69	11.85	17.17	3.47	4.45	7.01	9.93	12.36
	Shanxi	0.00	1.36	0.96	1.11	1.91	1.10	1.31	2.67	2.12	2.49	3.54	3.24	1.68
Northeastern Region	Heilongjiang	0.00	0.00	0.00	0.00	11.44	2.48	5.16	7.51	6.92	6.50	7.17	6.43	4.12
	Jilin	3.42	5.59	5.42	5.90	7.15	7.47	6.14	9.54	3.84	3.95	3.39	2.96	5.18
	Liaoning	3.30	5.05	5.41	5.79	4.48	3.72	2.09	2.03	2.02	1.64	1.46	4.30	3.35

As can be seen from *Table 3* and *Figure 2*, China's industrial water-saving potential showed an overall downward trend from 2004 to 2016, which indicates that with the accumulation of pollution treatment experience and the improvement of industrial water-saving technology over the years, China's industrial water resource green efficiency has been continuously improved. But industrial water-saving potential rebound in 2016, it showed that the gap of GEIWR among provinces has a declining trend. Provinces at the forefront of the GEIWR saw a smaller decline and maintained their leading level. However, provinces with low efficiency are restricted by many factors, such as water resource and management, and the decline rate is large, which caused the gap between them and frontier cities further widened. These provinces have a large space to improve industrial water saving in the future. Most of the provinces in central China, such as Hubei, Sichuan and Hunan, have a large space to tap the industrial water-saving potential. The governments of these regions should strengthen their drainage monitoring capacity, increase the intensity of industrial waste water treatment, and actively promote renewable water conservancy to improve the GEIWR.

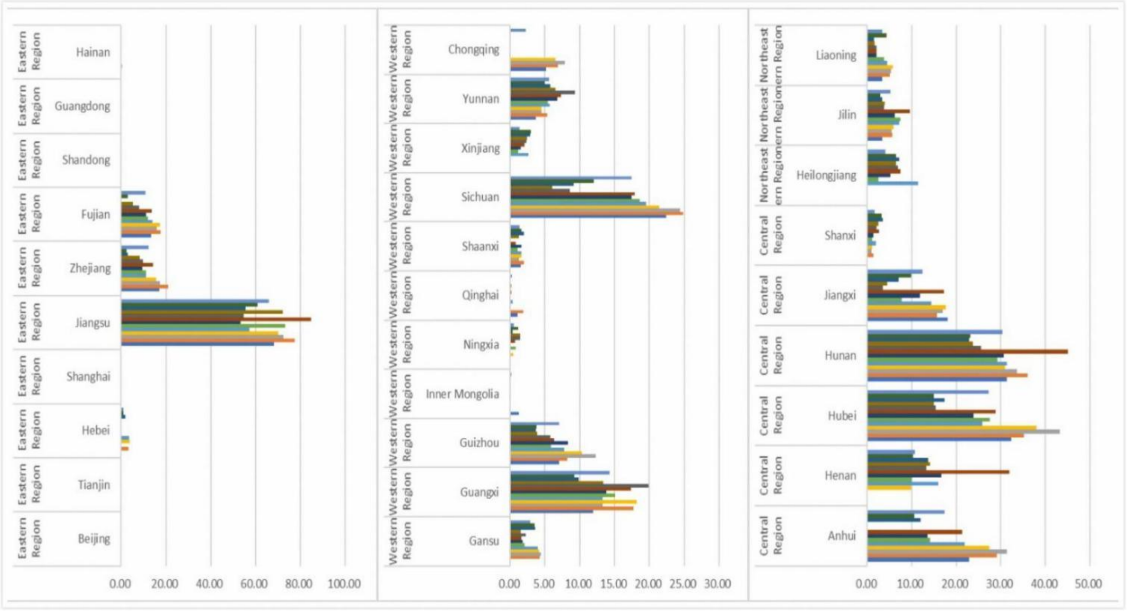

Figure 2. *Industrial water-saving potential of each region in China from 2004 to 2016*

Analysis on the influencing factors of GEIWR

We took the GEIWR in various provinces across the country from 2004 to 2016 as the explained variable; selected six indicators including Environmental Regulation (Government Waste Water Control), Technological Progress, Regional Characteristics[3], Industrial Structure (Industrial Structure Proportion), Foreign Capital Utilization (Foreign Trade Dependence) and Water Resource Consumption (Industrial Blue Water Footprint) as explanatory variables.

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[3] Seen by the analysis results, there are obvious regional differences in China's green efficiency of industrial water resource. So we introduces dummy variable (0 represents the eastern region and 1 represents the central, western and the northeast regions) to reflect the influence of region on the green efficiency of industrial water resource.

Because the explanatory variable value of regression equation is between 0 and 1, which is a limited dependent variable, this paper uses the panel Tobit model to test the efficiency effect mechanism. With the help of Stata software, the estimation results of Tobit regression model are obtained by using the maximum likelihood estimation (MLE) method, and are shown in *Tables 4* and 5.

Table 4. *Descriptive statistics*

Variable	Sample size	Mean	Standard deviation	Minimum	Maximum
Green efficiency of industrial water resources	390	0.840,4	0.159,1	0.3100	1.0000
Environmental regulation	390	0.115,5	0.118,9	0.0015	0.955,1
Technological progress	390	0.409,5	0.496,6	0.0000	2.601,8
Regional characteristics	390	0.666,7	0.4720	0.0000	1.0000
Industrial structure	390	40.171,2	8.193,9	11.904,2	56.491,6
Foreign capital utilization	390	31.644,6	36.781,5	1.343,9	187.500,4
Water resource consumption	390	379,480.6	405,716.7	128,52	227,748,3

Table 5. *The regression results of panel Tobit model*

Explanatory variable	Regression coefficient	Standard deviation	T-value	P > |t|
Environmental regulation	-0.243,4***	0.088,8	-2.74	0.006
Technological progress	0.091,4**	0.037	2.47	0.014
Regional characteristics	-0.213,4***	0.038,6	-5.52	0
Industrial structure	0.005,5***	0.001,5	3.58	0
Foreign capital utilization	0.001,9***	0.000,7	2.77	0.006
Water resource consumption	-1.95E-07***	3.07E-08	-6.35	0
Constant	0.844,8***	0.071,4	11.83	0
LR chi2(6)	206.22***			
Pseudo R2	0.730,6			
Log likelihood	-38.025,597			

***, **, * means that the variables are significant at the level of 1%, 5% and 10%, respectively

According to the regression results in *Table 5,* the influence mechanism of each factor is analyzed as follows:

(1) Although Environmental Regulation passed the significance test of 1% level, the regression coefficient was negative, which did not promote the improvement of the GEIWR. Generally speaking, increasing environmental regulation is conducive to the improvement of water resource efficiency. However, the regression results do not support this point. The main reason may be that the current government waste water control system is not perfect and the implementation effect is not satisfactory. The government should consider improving the waste water control system to better play the role of policy guidance.

(2) Technological Progress plays a role in promoting the GEIWR to some extent, but do not passed the significance test of 1% level. The positive impact is general.

(3) Regional Characteristic is significant at the 1% level, which shows that regional differences have a very significant impact on the GEIWR (Chen et al., 2016). However,

the coefficient is negative, probably because the Inner Mongolia, Qinghai in the western region and other regions, despite the lack of water resource and the low level of economic development, have a higher proportion of water resource per capita, a more reasonable industrial structure and a better utilization and allocation of industrial water resource. Meanwhile, some provinces in the central region are constantly developing heavy industry, and problems such as high investment in water resource and high pollution arise. The GEIWR of these provinces is often low.

(4) The increase of the industrial structure proportion has a significant positive effect on promoting the GEIWR. The coefficient of the regression model is positive and significant at the level of 1%. The greater the industrial structure proportion, the greater the investment in the treatment of industrial water pollution, and the higher the GEIWR.

(5) The improvement of Foreign Capital Utilization has a positive impact on the GEIWR, and has passed the significance test at the 1% level.

(6) Although the Industrial Water resource Consumption passes the significance test of 1% level, its regression coefficient is negative, indicating that the increase of industrial water consumption does not promote the GEIWR. This is consistent with the fact that in the actual industrial development, the greater the industrial water consumption, the greater the cost of water resource paid by the industrial development. Therefore, effectively reducing industrial water resource consumption is an important way to improve the GEIWR.

Conclusions, suggestions and discussion

Conclusions and suggestions

In this paper, EBM model was used to objectively analyze and explore the development trend of the GEIWR in 30 provinces from 2004 to 2016, and it was found that the efficiency was differentiated in both time and space. From the perspective of time, the GEIWR in different regions showed different development trends during the period. Thereinto, the GEIWR in Beijing, Tianjin, Shanghai, Guangdong and other regions has maintained a stable and effective state, while efficiency in Yunnan, Sichuan and other regions has been low year by year, so there is a certain space to tap their water-saving potential. From the perspective of space, China's GEIWR has the problem of "central collapse", and the eastern region's efficiency is generally higher than the other regions'. This proves that the developed social services and industrialization level in the eastern region provide certain support for its higher efficiency. The overall low GEIWR in the central region is due to the continuous development of heavy industry in the central region since the implementation of the "rise of the central region" strategy in 2003. Along with the rapid economic growth, problems such as high investment in water resource and high pollution have also emerged. The green development of industrial water resource in the central region is worthy of attention. From the impact mechanism analysis results, increasing the proportion of industrial industry and expanding the utilization of foreign capital are acting the important role in promoting the GEIWR. However, the government's efforts in waste water control and the increase of industrial water consumption have significantly inhibited the improvement of efficiency. Technological progress, although there is a positive effect, the promoting impact is not obvious. Based on the above conclusions, on the premise of ensuring the gradual improvement of the GEIWR and realizing the coordination of economy, society and environment, we put forward the following two suggestions.

(1) In view of the regional differences in China's GEIWR, each province should not cut at one stroke in dealing with problems, give full play to their regional characteristics, launch industrial water use strategy and water pollution prevention and control countermeasures in line with their own needs, so as to effectively improve the GEIWR. On the premise of ensuring the maximization of economic output and the minimization of environmental pollution, for provinces where the green efficiency of water resource has reached DEA efficiency, such as Beijing and Shanghai, the existing achievements should be consolidated, the steady economic and social development should be promoted, and the frontier level of GEIWR should be maintained. For provinces where the green efficiency of water resource is in the middle level, such as Jilin, Fujian and other regions should further improve the quality of economic growth, strengthen the guidance for the development of high-tech industries, limit the development of pollution-intensive industries, effectively reduce the intensity of industrial water, and improve the comprehensive service capacity of society on the basis of the achieved level. Provinces with low efficiency, such as Guangxi, Sichuan and other places should vigorously develop the economy, improve water management consciousness and ability, prefect the system of local government environmental regulation, develop water-saving potential on the basis of economic prosperity and development, emphasizes the synchronous development of the society to promote its positive role in GEIWR.

(2) In order to shorten the gap in the GEIWR among China's provinces, each province should break the regional blockade, avoid protectionism, increase the communication and cooperation in the field of industrial water-saving and water pollution prevention and control, optimize the industrial economic development pattern, and promote the coordinated development of all provinces.

Discussion

The study on the GEIWR is a complex and valuable subject with broad prospects. Indeed, regions with effective GEIWR are not completely devoid of water-saving space, and their water-saving potential still needs to be further explored. Moreover, there are many potential con-founders that could cause one region to be more efficient than another, including social factors, population health factors, environmental factors, and other economic factors. These factors may impact the GEIWR, and this issue warrants further investigation. Therefore, in terms of research methods, further research on EBM model and measurement ideas of water-saving potential can be carried out in the future to innovate research methods. In terms of research content, we can further enrich the content of the indicator system, such as exploring the impact on the GEIWR from the aspects of water resource price and tax.

Acknowledgments. This paper is supported by Jiangxi Humanities and Social Sciences Research Project (TJ161002), The Scientific Research Project of Jiangxi University of Finance and Economics (xskt18475), Student project of "The Marxist Youth Training Project" of Jiangxi University of Finance and Economics in 2019 (2019102509183036).

Conflict of interests. The authors declare no conflict of interests.

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