Research on the Measuring Method of Total Factor Fossil Energy Efficiency from the Perspective of Green Growth

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Abstract. This paper integrated systematically the method of MFA, DEA, and the evaluation method of eco-efficiency, constructed a method of measuring total factor fossil energy efficiency based on the perspective of green growth. And it defined the indicator system of evaluating total factor fossil energy efficiency. This paper gave an empirical research of total factor fossil energy efficiency, economic efficiency of fossil energy, environmental efficiency of fossil energy, and eco-efficiency of fossil energy, of Chinese provincial regions for the year 2013.Study results confirms: the method of measuring total factor fossil energy efficiency of this paper, not only discussed the measuring problem of total factor fossil energy efficiency of the process of fossil energy using, but also brought economic value, environmental influence and ecological cost into measuring framework of total factor fossil energy efficiency; so it is a scientific and comprehensive method of measuring fossil energy efficiency, and is in conformity with the idea of green growth.

Keywords: fossil energy efficiency; science and technology resources; material flow analysis; green growth; hidden flows.

1. Introduction

At present, the main part of energy on the world is still coal, oil and natural gas, as well as other fossil energy, and global fossil energy is increasing depletion, mankind is facing the increasingly serious energy crisis. Green growth is the inevitable choice for the sustainable development of human society. The fossil energy, environment, ecology and economic growth exist inseparable interactions.So, it is particularly important,to explore a total factor of fossil energy efficiency measurement method, in line with the concept of green growth and sustainable development,for a nation or region to enhance the overall utilization efficiency of fossil energy, to provide decision references and theory supports. This paper integrated systematically the method of MFA (Material Flow Analysis), DEA (Data Envelopment Analysis), and the evaluation method of eco-efficiency, constructed a method of measuring total factor fossil energy efficiency from the perspective of green growth, and gave an empirical research based on Chinese provincial regional data for the year 2013.

2. The related research review

2.1. The literature review of related problems

Hu and Wang [1], Chang and Hu [2], Shi [3] distinguished the concept of energy productivity and energy efficiency.Li and Hu [4] used DEA-SBM model, calculated and analyzed the total factor energy efficiency of China's provincial. Zhang, Cheng and Yuan, et al.[5]measured the total factor energy efficiency of 23 developing countries from 1980 to 2005. Honma and Hu[6]discussed Japan's regional total factor energy efficiency.Zhou and Ang [7],Zhou, Ang Zhou[8]explored the measurement problem of energy efficiency of the economic system.Giacone and Manc ò [9]discussed the measurement problem of energy efficiency of Industrial processes.Wang, Zhou and Zhou[10]measured and analyzed China's energy efficiency and productivity with non-radial direction distance function.He, Zhang and Lei, et al. [11]discussed the changes of energy efficiency and productivity in China's steel industry in the years 2001-2008 considering the case of undesirable outputs.Yang and Wang[12]estimated the China's provincial environmental efficiency of energy utilizing, and compared their differences, based

on provincial panel data and DEA method. Zou, Chen and Liu, et al.[13]researched the measurement and evaluation issues of China's regional energy efficiency based on provincial panel data.Lin and Du[14]discussed the relations of technology gap and regional energy efficiency of China with a common boundary parameters method.Wang, Zhao and Zhou, et al.[15]discussed regional energy efficiency and technology gap with the method which combined a common boundary and DEA.Honma and Hu[16]discussed total factor energy efficiency of the industrial sector in developed countries,in the case of Japan. Zhao, Yang and Ma [17] discussed the China's provincial industrial sector total factor energy efficiency, and other literatures, etc.

2.2. Limitations of existing research

(1)Total factor energy efficiency evaluation indicator system is imperfect. To analyse according to input indicators, no literature consider ecological damage during the energy developing and utilizing, little literature looked the science and technology resources as energy efficiency evaluation indicator. To analyze according to output indicators, many literature do not consider the environmental pollution problems of output terminal; or indicators of environmental pollutants is considered incompletely.

(2)Existing literature focuses on the overall energy efficiency mostly, but cannot measure accurately the fossil energy efficiency.

(3)Existing literature lacks of the evaluation method research of total factor energy efficiency integrate systematically MFA, DEA and eco-efficiency evaluation method.

(4) There are close interaction relations between energy, environment, ecology and economic growth, the existing literature lacks to put them into a unified analytical framework to consider.

This study made up for these shortcomings.

3. Constructing of measurement method of total factor fossil energy efficiency from the perspective of green growth

3.1. The MFA of fossil energy based on the perspective of Total Factor Productivity

Figure 1 is a MFA framework of fossil energy based on the perspective of TFP (Fotal Factor Productivity).

According to the Figure 1,we can determine input-output indicator of the total factor fossil energy efficiency measurement;and these indicators integrated properly, it can be combined with DEA model; then introduced of DEA method, and learned from the idea of eco-efficiency evaluation method; next, conducted a measurement of total factor fossil energy efficiency.

Some indicators need to integrate, regional fossil energy substances trade balance discount= fossil energy substances which region sold-fossil energy substances which region bought; therefore, the indicator of regional fossil energy substances trade balance discount, may replace the two indicator of fossil energy substances which region sold and fossil energy substances which region bought.

Thus, in the MFA framework of fossil energy, the input indicators is the various elements which are inputed in production; after combined with DEA model, these elements are input indicators of DEA model. In the MFA framework, the indicators of value increasing amount generated by the economic system, and the output indicators of the MFA of fossil energy, take together to correspond output indicators of DEA model.

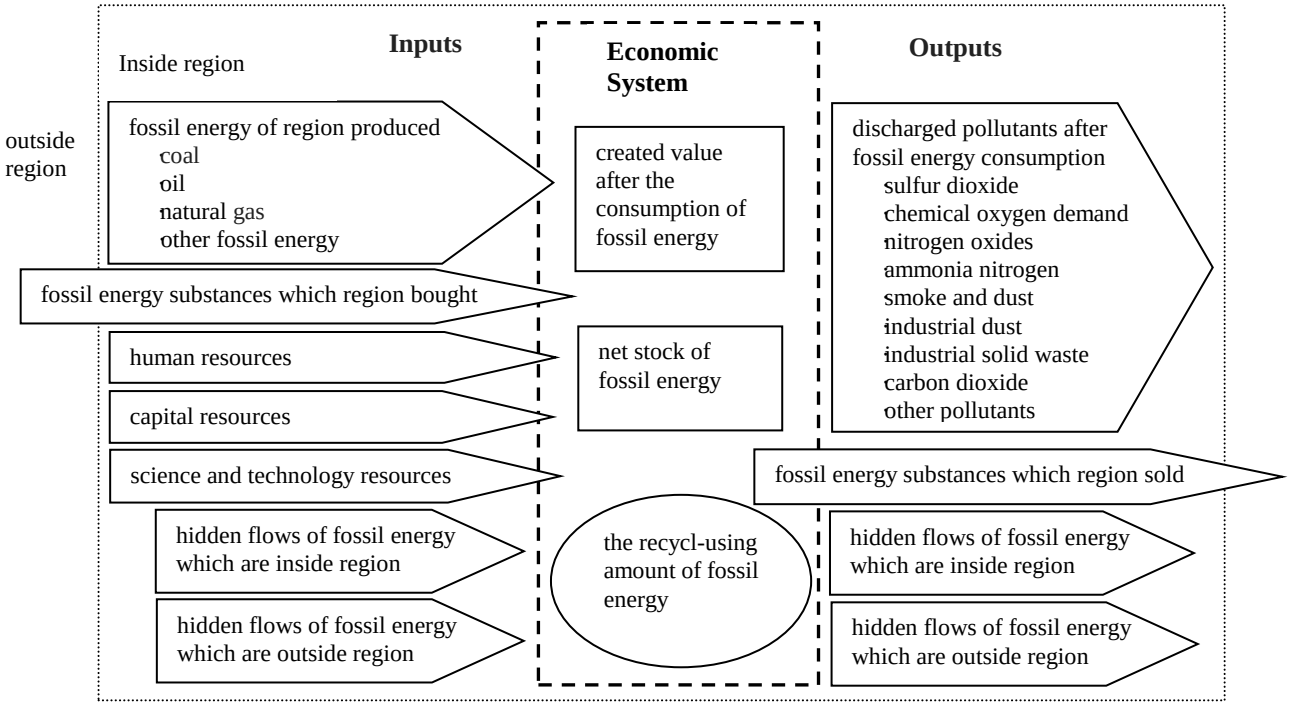

Fig.1 MFA framework of fossil energy based on the perspective of TFP

3.2. Construction of total factor fossil energy efficiency measureing method from the perspective of green growth

There is no unified and cleared definition of the concept of green growth in the world currently. The authors analysed systematicly the literature of green growth which is existing in the world, and found that the vast majority of research institutions and scholars, expresses the concept of green growth, contain basically the following idea: green growth is a nation or a region in the process of economic development, relying on scientific and technological progress, to make the consumption of non-renewable natural resources continue to decrease; and to develop vigorously renewable resources, alternative resources and new resource materials, in order to make then in the proportion of resource consumption increase gradually; to make environmental pollution and ecological destruction minimize, and to make created economic value maximize; so, it is an economic development pattern in line with the sustainable development concept. Although many research institutions and scholars defined the concept of green growth, focusing on different subject respectively, but reflected basically the concept of economic growth and resource, ecology, and environment coordinate developing.

Based on the statements of green growth concept above,this paper defined some concepts, which are as follows.Total factor fossil energy efficiency refers to, in the process of fossil energy mining, processing, using, and recycle-using, through investments of various elements, to make environmental pollution and ecological damage minimizing as the premise, to produce the degree of economic value maximization. Economic efficiency of fossil energy refers to, in the process of fossil energy mining, processing, using, and recycle-using, through investments of various elements, to create the degree of value maximization. Environmental efficiency of fossil energy refers to, in the process of fossil energy mining, processing, using, and recycle-using, through investments of various elements, to make minimization degree of pollutant emissions. Eco-efficiency of fossil energy learned from the idea of eco-efficiency evaluation method, it refers to in the process of fossil energy mining, processing, using, and recycle-using, with fewer natural resources investments to create greater value as the premise,simultaneously,to produce the minimization degree of ecological damage.

Figure 2 is the measurement method and indicators system framework of fossil energy efficiency from the perspective of green growth.

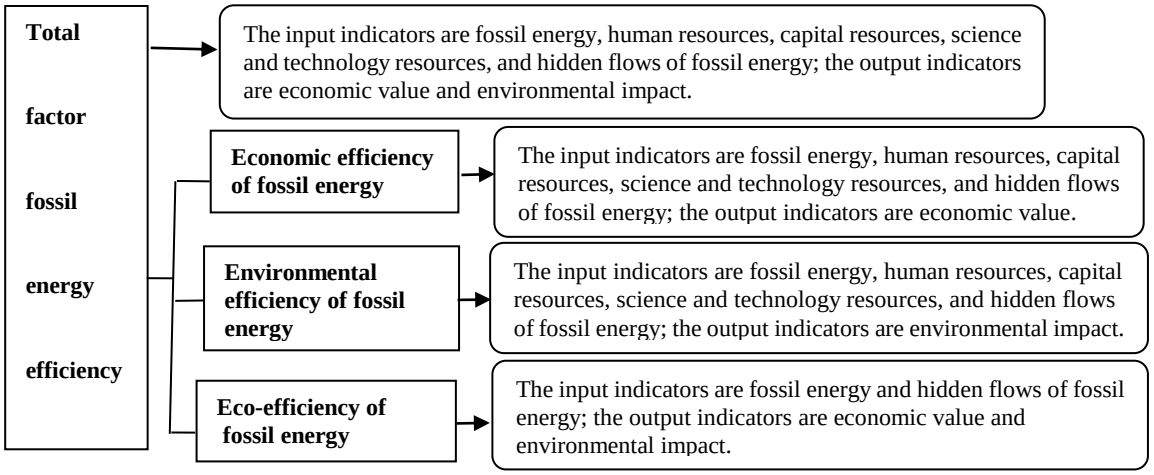

Fig.2 Measurement method and indicators system framework of fossil energy efficiency from the perspective of green growth

3.3. The DEA model of this paper used

This paper used a linear data transfer function method to transfer environmental pollutants (environmental impact), which are undesirable outputs, into the desirable outputs which can be used to account by DEA model, and that are positive environmental impact.

Assume there are no Decision Making Units(DMUs) which are independent of each other, each DMU has m types of input elements x_{ij} ,k types of output elements y_{ij} ,emits s types of environmental pollutants b_{tj} .Using linear data conversion functions $b_{tj}'=-b_{tj}+U\geq 0$,U is a enough large vector; thus, we can transform environmental pollutants(environmental impact) b_{tj} ,into positive environmental impact b_{tj}'.

This paper uses BCC model, which is as follows.

$$\begin{cases} \min\theta_0 \\ \text{s.t.} \quad \sum_{j=1}^{n}\lambda_j x_{ij}+s_i^{-}=\min\theta_0 x_{i0}, i=1,2,\ldots,m \\ \sum_{j=1}^{n}\lambda_j y_{rj}+s_r^{+}=y_{r0}, r=1,2,\ldots,k \\ \sum_{j=1}^{n}\lambda_j b_{tj}'+s_t^{+}=b_{t0}', t=1,2,\ldots,s \\ \sum_{j=1}^{n}\lambda_j=1 \\ \lambda_j, s_i^{-}, s_r^{+}, s_t^{+}\geq 0 \end{cases}$$

In this model, θ_0 represents the valid optimal solution, λ_j represents the combination coefficients, s_i^- represents inputs redundancy amount, s_r^+ and s_t^+ represents outputs insufficient amount.

4. The empirical test of total factor fossil energy efficiency measurement from the perspective of green growth

4.1. Sources of data in this paper

In Figure 2, the data accounting methods of various indicators of total factor fossil energy efficiency measurement is showed in table 1.

The data of various indicators described in table 1, derived from *China Statistical Yearbook (2014)*, Statistical Yearbook of Chinese various provincial regions in the year 2014, *2013Report on the State of the Environment in China* and other relevant statistical data.

Fixed capital stock of Chinese provincial region in the year 2013, calculated by the perpetual inventory method: that is, fixed capital stock of each region this year=the stock of fixed capital of region the year before × (1-the rate of depreciation of fixed assets) +fixed asset investment of region this year. The data of fixed assets investment of Chinese each provincial region in the year 2013,can find in *China Statistical Yearbook(2014)*,the data of fixed capital stock and the rate of depreciation of fixed assets, reference Jun Zhang, Gui-ying Wu and Ji-peng Zhang "The estimation of China's provincial capital stock: 1952—2000" measured the capital stock in the year 2000 as the basic data, then according to the formula calculated fixed capital stock data of Chinese provincial regions in the years 2001—2013.

The hidden flows data of unit standard coal, referenced Gang Li "Material Flow Analysis of Nations Based on Sustainable Development" had adopted hidden flows data of unit raw coal, and converted into the hidden flows of unit standard coal.

Emissions amount data of carbon dioxide, referenced to An-gang Hu, Jing-hai Zheng ,Yu-ning Gao, Ning Zhang, Hai-ping Xu "Provincial Technology Efficiency Ranking with Environment Factors (1999—2005) "had adopted method, then calculated, thus obtained it.

Table 1 the data accounting methods of various indicators of total factor fossil energy efficiency measurement

	first level indicators	**the data accounting method**	**second level indicators**	**the data accounting method**
input indicators	human resources(ten thousand people)	regional human capital stock	regional human capital stock	quantity of employment of provincial regional urban and rural
	capital resources (billion yuan)	regional fixed capital stock	regional fixed capital stock	calculated by the perpetual inventory method
	science and technology resources	Using the factor analysis method to synthesize R&D expenditure etc. three second level indicator to the science and technology resources comprehensive indicator.	R&D expenditure	directly obtained in statistical data
			local financial allocation on science and technology	directly obtained in statistical data
			The number of R&D personnel of thousands of people each year	directly obtained in statistical data
	fossil energy(ten thousand tons standard coal)	fossil energy produced in the region	fossil energy produced in the region	production amount of coal,oil and natural gas of the region,equivalent to amount of standard coal,then aggregate.
	hidden flows of fossil energy (ten thousand tons)	fossil energy produced in the region(equivalent amount of standard coal) ×the hidden flow of unit standard coal	fossil energy produced in the region	production amount of coal,oil and natural gas of the region,equivalent to amount of standard coal,then aggregate.
			the hidden flow of unit standard coal	calculated and got:the hidden flows of per ton standard coal is 13.29 tons
output indicators	economic value(ten thousand yuan)	the total value of the region created this year	the total value of the region created this year	GDP of the region this year
	positive environmental impact	Using factor analysis method to synthesize sulfur dioxide etc.eight second level indicator to the environmental impact indicator b_1 ,then using linear data conversion functions, $b_1' = -b_1 + W$,to convert,thus got positive environmental impact indicator b_1' .	emission amount of sulfur dioxide	total emission amount of sulfur dioxide of industry sources,the sources of life,and centralized pollution treatment facilities this year.
			emission amount of chemical oxygen demand	total emission amount of chemical oxygen demand of industry sources,the sources of life,agricultural sources and centralized pollution treatment facilities this year.
			emission amount of nitrogen oxides	total emission amount of nitrogen oxides of industry sources,the sources of life,motor vehicle and centralized pollution treatment facilities this year.
			emission amount of ammonia nitrogen	total emission amount of ammonia nitrogen of industry sources,the sources of life,agricultural sources and centralized pollution treatment facilities this year.

			emission amount of smoke and dust	total emission amount of smoke and dust of industry sources,the sources of life this year.
			emission amount of industrial dust	directly obtained in statistical data
			emission amount of industrial solid waste	directly obtained in statistical data
			emission amount of carbon dioxide	consumption amount of carbonaceous energy×the carbon conversion coefficient×carbon dioxide gasification coefficient

a) Measurement result and analysis in this paper

According to Figure 2 and Table 1, we can get the data of input and output indicators of this paper.combine these data and the selected DEA model, using the common software DEAP2.2, measured total factor fossil energy efficiency, economic efficiency of fossil energy, environmental efficiency of fossil energy, and eco-efficiency of fossil energy, of Chinese provincial regions in the year 2013.Table 2 is the measured results.

To analyze the various data in Table 2 below.

Total factor fossil energy efficiency

Total factor fossil energy efficiency of Chinese provincial regions present basically the "under the ladder" distribution which reduces gradually from southeast to northwest. Total factor fossil energy efficiency of Beijing,Tianjin,Shanghai,Jiangsu,Zhejiang,Fujian,Guangdong,Hainan is DEA effective, and these provincial regions form production frontier of total factor fossil energy efficiency, belong to the first echelon. The main reasons are that these province economic development level is relatively high, got substantial improvement in their level of technology and production processes, mostly carried out upgrading of industrial structure, to develop mainly low energy consumption, high value-added industries, high-tech industries and the services is relatively developed;attached importance to the development of renewable energy and new energy, pay attention to the products development and application of saving energy and environmental protection, thus, fossil energy efficiency got improved. Total factor fossil energy efficiency of Jiangxi, Anhui, Guangxi, Shandong is relatively high, belong to the second echelon. Henan, Shaanxi, Chongqing, Hunan belong to the third echelon, is the medium level. Northeast (Heilongjiang, Jilin, Liaoning)basically belong to the fourth echelon, is a lower middle level.The main reason is that the northeast is the heavy industry base of China, leading industries are more concentrated in high energy consuming industries, such as, machinery manufacturing,energy development,chemical, metallurgy and building materials industries, etc, therefore, lead to excessive energy consumption; at the same time, saving energy mechanism is not perfect, which leads to the low fossil energy efficiency. Hubei, Sichuan, Yunnan, Hebei, Gansu, Xinjiang, Inner Mongolia, Guizhou belong to the fifth echelon. Total factor energy efficiency of Ningxia, Qinghai, Tibet, Shanxi is the lowest, belong to the sixth echelon. The main reason of Ningxia, Qinghai, Tibet, is the less developed economy, technology and equipment is relatively backward, resulting in low fossil energy output efficiency.Shanxi is a big province of coal production, consumption of coal and coke in industrial production is larger, while saving energy mechanism is not perfect, which leads to the low fossil energy efficiency.

(2) Economic efficiency of fossil energy

Economic efficiency of fossil energy and total factor fossil energy efficiency of the provincial regions showed basically a positive correlation. The regions of total factor fossil energy efficient is high, correspondingly, economic efficiency of fossil energy is relatively high. Beijing, Tianjin, Shanghai, Jiangsu, Zhejiang, Guangdong, Fujian, these provincial regions, relatively lack of resources, but economic efficiency of fossil energy is the highest in China. The western region is rich in natural resources, while economic efficiency of fossil energy is far lower than the eastern region. The region with abundant natural resources need avoid a single economic structure which depended on excessively resource; to use resources to exchange necessary capital for sustained economic growth. With the capital, to continue to seek innovative development pattern, to transform to green growth pattern which is low energy consumption, low emissions, less pollution; to transform to a diversified

economic structure and industrial structure. The regions should rely on scientific and technological progress, to promote resource conservation, with less resource consumption, to create greater economic development; to make resources become the necessary material condition of creating new economic growth continuously.

(3)Environmental efficiency of fossil energy

Most of the provincial regional environmental efficiency and eco-efficiency of fossil energy is lower than the economic efficiency of fossil energy. This shows that many regions of China is rapid in economic growth, at the same time, environmental pollution and ecological damage is very seriously. Rapid economic growth is at the cost of environmental pollution and ecological damage. The key problem is that local governments and enterprises have not established firmly the concept of green growth, have not established the idea of ecological civilization, pay attention to economic growth and economic output, but underrate environmental protection.

regional environmental efficiency of fossil energy closely related to total factor fossil energy efficiency.Guangdong,Jiangsu,Hainan,Tianjin,Beijing,Shanghai,Guangxi,Zhejiang,Fujian,environmental efficiency of fossil energy of these provincial regions is the highest. Mainly because economic development foundation for a long time in these regions is better, and these regions attach importance to the optimization and upgrading of industrial structure; the investment on environmental governance is comparative large, thus, protected effectively the natural environment and the living environment. Environmental efficiency of energy of Shanxi, Ningxia, Qinghai, Xinjiang, Gansu is the lowest, because the level of economic development of these regions is relatively low, and economic foundation and strength is relatively weak, and technology is backward, and leading industry is high emission and large pollution; in terms of environmental inputs and environmental governance have many deficiencies. These provincial regions need to increase continuously the efforts of environmental protection, and improve continuously environmental quality.

(4) eco-efficiency of fossil energy

Eco-efficiency of fossil energy and environmental efficiency of fossil energy is positive correlation. This shows that the ecological damage and environmental pollution often has great relevance, ecological damage in the process of energy development and utilization often leads to environmental pollution; and pollution of the environment, but also often leads to ecosystem destruction which is original good. Therefore, China must strengthen ecological protection awareness, in the process of fossil energy development and utilization, to exploit legitimately natural resources, and to avoid predatory exploitation of natural resources; for some lean ore resources which is little mining value, to implement protective measures of mine closure; and to minimize ecological damage for these mineral resources which is ready to develop; for those mineral resources which has been abandoned, need to implement the measures of recovery and reconstruction of ecosystem; to strive to reduce hidden flows(ecological rucksacks) in the process of fossil energy development and utilization.

Table2 total factor fossil energy efficiency, economic efficiency, environmental efficiency and eco-efficiency of fossil energy of Chinese provincial regions in 2013

geographical district	provincial region	total factor fossil energy efficiency	economic efficiency of fossil energy	environmental efficiency of fossil energy	eco-efficiency of fossil energy
North China	Beijing	1.000	1.000	0.845	1.000
	Tianjin	1.000	1.000	0.853	1.000
	Hebei	0.764	0.759	0.634	0.687
	Shanxi	0.697	0.685	0.479	0.531
	Inner Mongolia	0.721	0.713	0.602	0.692
Northeast China	Heilongjiang	0.819	0.814	0.740	0.793
	Jilin	0.828	0.821	0.743	0.785
	Liaoning	0.812	0.806	0.745	0.768
East China	Shanghai	1.000	1.000	0.826	1.000
	Jiangsu	1.000	1.000	1.000	0.923
	Zhejiang	1.000	1.000	0.813	0.931
	Anhui	0.939	0.931	0.736	0.819
	Fujian	1.000	0.972	0.772	0.904
	Shandong	0.925	0.917	0.739	0.836
	Jiangxi	0.958	0.954	0.735	0.847

Central China	Henan	0.923	0.905	0.681	0.802
	Hubei	0.817	0.813	0.624	0.758
	Hunan	0.851	0.836	0.623	0.766
South China	Guangdong	1.000	1.000	1.000	0.935
	Guangxi	0.934	0.921	0.819	0.903
	Hainan	1.000	0.953	0.926	1.000
Southwest China	Chongqing	0.861	0.850	0.727	0.812
	Sichuan	0.802	0.782	0.653	0.769
	Guizhou	0.708	0.684	0.632	0.676
	Yunnan	0.765	0.753	0.714	0.750
	Tibet	0.633	0.626	0.617	0.625
Northwest China	Shaanxi	0.874	0.865	0.638	0.761
	Gansu	0.737	0.731	0.596	0.638
	Qinghai	0.656	0.642	0.528	0.575
	Ningxia	0.579	0.568	0.485	0.562
	Xinjiang	0.723	0.714	0.541	0.613

5. Conclusions

This paper integrated systematically the method of MFA, DEA, and the evaluation method of eco-efficiency, constructed a method of measuring total factor fossil energy efficiency from the perspective of green growth; and gave an empirical research of total factor fossil energy efficiency, economic efficiency of fossil energy, environmental efficiency of fossil energy, and eco-efficiency of fossil energy, of Chinese provincial regions for the year 2013.

The total factor fossil energy efficiency measurement method of this paper constructed, is a more scientific and comprehensive measurement method of fossil energy efficiency which is conforming the concept of green growth. This method not only has considerable theoretical significance, but also has considerable practical significance. It can be used to measure total factor fossil energy efficiency, for a nation or region to enhance the overall utilization efficiency of fossil energy, implement green growth pattern, and provide decision references and theory supports.

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