Study on Assessment Approach of Total Factor Resource 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, contracted an assessment approach of total factor resource efficiency from the perspective of green growth. And it defined the indicator system of assessing total factor resource efficiency. This paper gave an empirical study of total factor resource efficiency, economic efficiency of resource, environmental efficiency of resource, and eco-efficiency of resource, of Chinese provincial regions for the year 2012.Study results confirms: the assessment approach of total factor resource efficiency of this paper contracted, not only discussed the assessing problem of total factor resource efficiency of the process of natural resources using, but also brought economic value, environmental influence and ecological cost into assessing framework of total factor resource efficiency; o it is a scientific and comprehensive approach of assessing natural resources efficiency, and is in conformity with green growth theory.

Keywords: total factor resource efficiency; science and technology resources; material flow analysis; green growth; natural resources

1. Introduction

Natural resources is the lifeblood of human society survival and development, while the natural resources are increasingly exhausted.

Green growth is the inevitable choice for the sustainable development of human society. The natural resources, environment, ecology and economic growth exist inseparable interactions.So, it is particularly important,to explore a total factor resource efficiency assessment approach,in line with green growth theory,to assess effectively efficiency problems of the process of natural resources extraction, processing, using and recycle-using, for a nation or region to enhance the overall utilization efficiency of natural resources, and to develop green growth or sustainable development pattern,and 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, contracted an approach of assessing total factor resource efficiency from the perspective of green growth, and gave an empirical study based on Chinese provincial regional data for the year 2012.

2. The related research review

2.1. The literatures review of related problems

Resource Efficiency and Resource Productivity is the most common and most easily confused words in the related research fields of resource efficiency.The related literatures review of Resource Efficiency and Resource Productivity are as follows.

Pearce put forward calculation method of resource productivity, that is, resource productivity is equal to the ratio of the amount of economic outputs and resource substance inputs [1]. Dahlström and Ekins studied disparities between resource efficiency and resource productivity in steel and aluminum industry in the UK [2]. Schandl and West discussed resource use and resource efficiency issues in Asia-Pacific region in the years 1970-2005, using IPAT framework [3]. Bleischwitz studied the resource productivity related issues: conjunction, measurement, empirical tendencies, innovation, and resource policies [4]. Bian and Yang discussed Chinese provincial resource and environmental efficiency based on Shannon's Entropy [5]. Strazza etc. explored the role of improving resource productivity for promoting cleaner production [6]. Ang etc. discussed sustainable development issues from the perspective of the overall resource efficiency of EU-15 countries [7]. Guo etc. discussed change tendencies and reasons of Metropolitan resources efficiencies in China[8].Barrett and Scott researched the relationship between climate change alleviation and resource efficiency taking UK as an example[9].Delmas and Pekovic studied the role of companies implement resource efficiency strategy under different market conditions[10].Von Weizsäcker and Ayres explored the relationship between resource productivity and resource pricing[11].Samus etc. explored assessment problems of natural resource forth putting and resource efficiency potential[12]. Rosen discussed the evaluation of global resource use efficiency in the industrial sector [13].Yang etc. discussed the application of composite efficiency indicators in the evaluation of resource and energy [14]. Brennan and Palmer studied Energy efficiency resource standards from the perspective of economics and policy [15].Hoang analyzed resource efficiency of 116 economies with a production frontier approach [16]. Rohn etc. discussed the role of technology, products and strategies for mining the potential of resource efficiency [17]. Du etc. discussed fixed costs and resource allocation with DEA cross-efficiency [18].Massarutto researched the role of extended producer responsibility for enhancing resource efficiency [19]. Figge etc. discussed the problem of rebound effect in resource efficiency [20], and other literatures, etc.

2.2 Limitations of existing research

(1)Total factor resource efficiency assessment indicator system is imperfect. Most scholars use resource productivity instead of resource efficiency. The concept of resource productivity has a great limitations: resource productivity measure the ratio of the created value after natural resources consumption and the inputs of natural resources; neither take into account the influence of other input factors in production, nor take into account environmental pollution and ecological damage in the process of natural resources exploitation and utilization.

(2)Existing literature lacks of the assessment approach study of total factor resource efficiency integrate systematically MFA, DEA and eco-efficiency evaluation method.

(3)There are close interaction relations between natural resources, environment, ecology and economic growth, the existing literature lacks to put them into a unified analysis framework to consider.

This study made up for these shortcomings.

3. Constructing of assessment approach of total factor resource efficiency from the perspective of green growth

3.1. The MFA of natural resources based on the perspective of Total Factor Productivity

At present, most scholars use resource productivity instead of resource efficiency. The concept of resource productivity has a great limitations: resource productivity measure the ratio of the created value after natural resources consumption and the inputs of natural resources, neither take into account the influence of other input factors in production, nor take into account environmental pollution and ecological damage in the process of natural resource exploitation and utilization; so, it is single factor resource efficiency. In order to make up for these shortcomings,this paper defined the concept of total factor resource efficiency, that is: in the process of natural resources mining, processing, using, and recycl-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; it is based on the theory of total factor productivity; it consider entirely of the impact of input factors in production, such as natural resources, human resources, capital resources,science and technology resources,and hidden flows of natural resources; and it consider entirely of the impact of output factors, not only have economic output, but also have the impact of environment.

Figure 1 is the concept framework of resource efficiency.

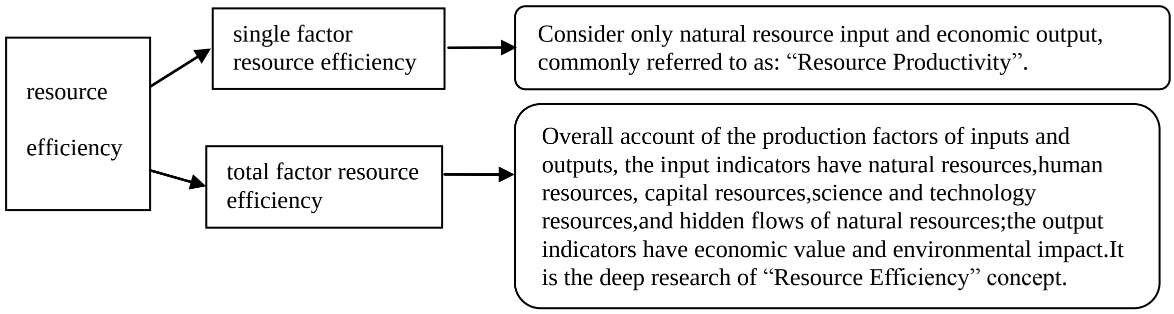

Fig. 1 Concept Framework of Resource Efficiency

Figure 2 is a MFA framework of natural resources based on the perspective of TFP (Fotal Factor Productivity).

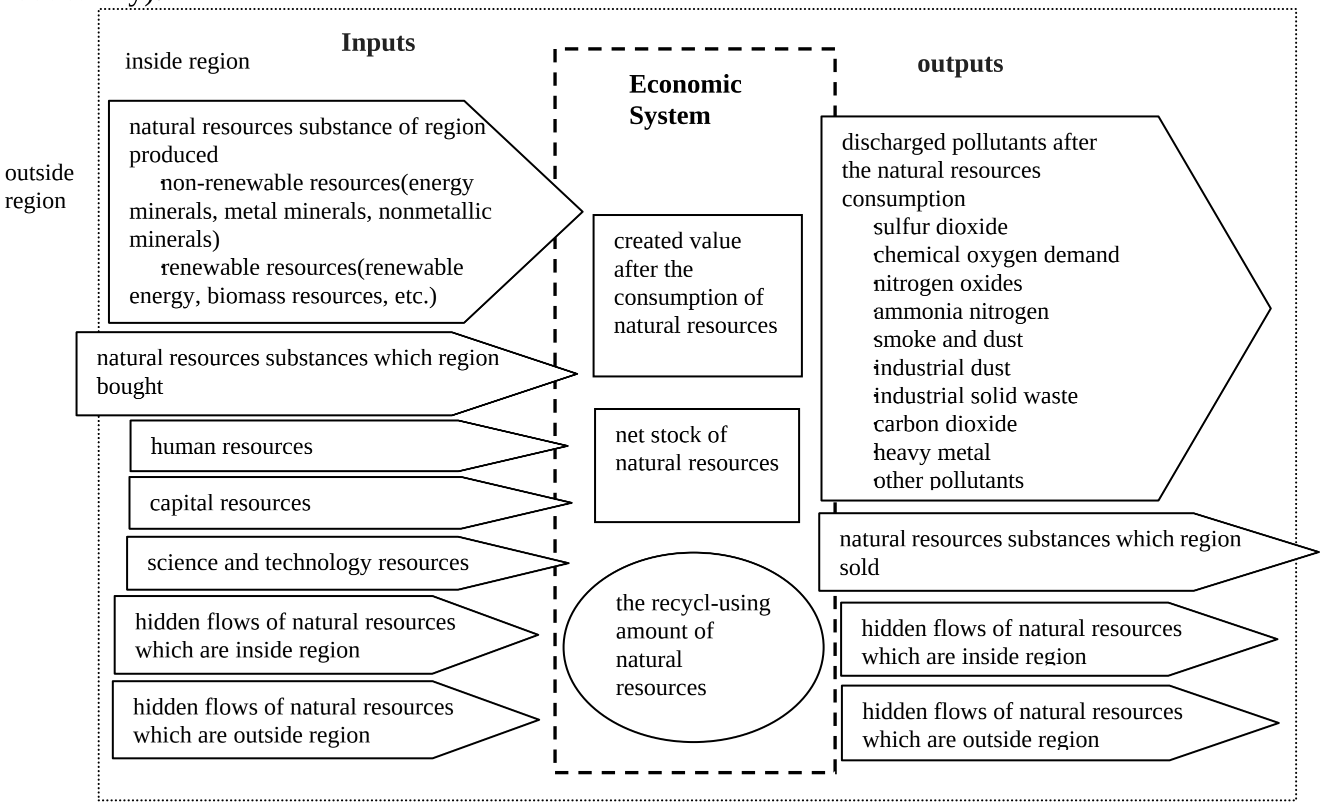

Fig. 2 MFA framework of natural resources based on the perspective of TFP

According to the Figure 2, we can determine the input-output indicators of the total factor resource efficiency assessing; 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 an assessment approach of total factor resource efficiency.

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

Thus, in the MFA framework of natural resources, the input indicators are the various elements which are inputted in production; after combined with DEA model, these elements are input indicators of DEA model. In the MFA framework, the indicators of value increased amount generated by the economic system, and the output indicators of the MFA of natural resources, take together to correspond output indicators of DEA model.

3.2 Construction of total factor resource efficiency assessment approach 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 analyzed systematically 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 substance, in order to make them 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, environment coordinate developing.

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

Figure 3 is the assessment approach and indicators system framework of total factor resource 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 n 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.

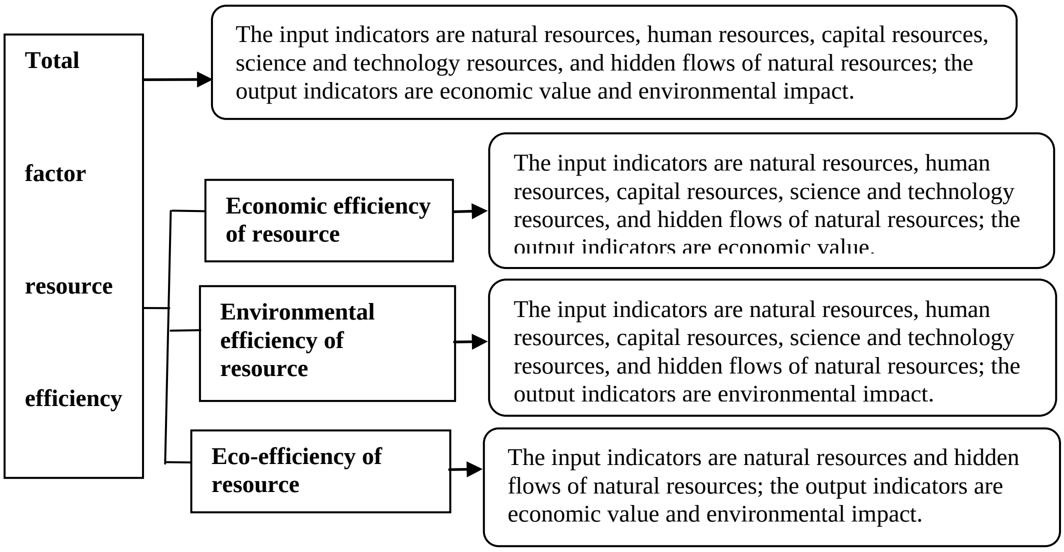

Fig. 3 Assessment approach and indicators system framework of total factor resource efficiency from the perspective of green growth

4. The empirical test of total factor resource efficiency assessment from the perspective of green growth

4.1. Sources and accounting methods of data in this paper

In Figure 3, the data accounting methods of various indicators in this paper is showed in table 1.

The data of various indicators described in table 1, derived from *China Statistical Yearbook (2013)*, Statistical Yearbook of Chinese various provincial regions in the year 2013, *China Science and Technology Statistical Yearbook (2013), China Energy Statistical Yearbook (2013), China Mining Yearbook (2013), China environment statistical Yearbook (2013), 2012 Report on the State of the Environment in China* and other relevant statistical data.

Fixed capital stock of Chinese provincial region in the year 2012, 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 2012,can find in *China Statistical Yearbook(2013)*,the data of fixed capital stock and the rate of depreciation of fixed assets, reference Jun Zhang, Guiying Wu and Jipeng 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—2012.

The hidden flows data of unit non-renewable resources, referenced Gang Li "Material Flow Analysis of Nations Based on Sustainable Development", and converted, thus got the hidden flows data of unit standard coal, unit metal minerals and unit nonmetallic minerals.

Emissions amount data of carbon dioxide, referenced to Angang Hu, Jinghai Zheng, Yuning Gao, Ning Zhang, Haiping Xu "Provincial Technology Efficiency Ranking with Environment Factors (1999— 2005) "had adopted method, then calculated, thus obtained it.

This paper measured heavy metal pollutant emissions of Chinese provincial regions take the following methods. According to the Chinese *the first national census of pollution sources: produce and emission coefficient manual (2010 revision) of industrial pollution sources* and *the first national census of pollution sources: produce and emission coefficient manual (2010 revision) of urban domestic sources*. According to the year 2012 the metal minerals yield data of Chinese provincial regions, and industrial wastewater discharges and treatments in a variety of industries data in the year 2012 of Chinese provincial regions, and industrial waste gas discharges and treatment in a variety of industries data in the year 2012 of Chinese provincial regions,and industrial solid waste discharges and treatment in a variety of industries data in the year 2012 of Chinese provincial regions, this paper measured lead, cadmium, arsenic, mercury, hexavalent chromium, nickel, zinc, copper, the eight kinds of typical heavy metal pollutant emissions.Using factor analysis method to synthesize the eight kinds of typical heavy metal pollutant emissions to one indicator, combined with the magnitude of the eight heavy metal pollutants, obtained the composite indicator data of heavy metal pollutant emissions after the weighted in the year 2012 of Chinese provincial regions.

Table 1 the data accounting methods of various indicators in this paper

	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 indicators to the science and technology resources composite indicator.	R&D expenditure	direct obtained in statistical data
			local financial allocation on science and technology	direct obtained in statistical data
			the number of R&D personnel of thousands of people this year	direct obtained in statistical data
	natural resources (ten thousand tons)	the amount of natural production in the region	the amount of natural production in the region	the amount of non-renewable resources substances production in the region+the amount of renewable resources substances production in the region
	hidden flows of natural resources (ten thousand tons)	the hidden flows of non-renewable resources	the hidden flows of non-renewable resources	the hidden flows of energy minerals+the hidden flows of metal minerals+the hidden flows of nonmetallic minerals
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. nine 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
			emission amount composite indicator of heavy metal	to measure lead,cadmium,arsenic, mercury,hexavalent chromium,nickel, zinc,copper,the eight kinds of typical heavy metal pollutant emission amount,then to form emission amount

				composite indicator of heavy metal

4.2. Assessment results and analysis of this paper

According to Figure 3 and Table 1, we can get the data of input and output indicators of this paper, using the common software DEAP 2.2, assessed total factor resource efficiency, economic efficiency of resource, environmental efficiency of resource, and eco-efficiency of resource, of Chinese provincial regions in the year 2012.Table 2 is the assessed results.

To analyze the various data in Table 2 below.

(1)Total factor resource efficiency. Total factor resource efficiency of Chinese provincial regions present basically the “under ladder” distribution which reduces gradually from southeast to northwest. Total factor resource efficiency of Beijing, Tianjin, Shanghai, Jiangsu, Zhejiang, Fujian, Guangdong, Hainan is DEA effective, and these provincial regions form production frontier of total factor resource 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 and resource consumption, high value-added industries, high-tech industries and the services is relatively developed; attached importance to the development of renewable resource and new energy, pay attention to the products development and application of conserving resource and protecting environment, thus, resource efficiency got improved. Total factor resource efficiency of Jiangxi, Anhui, Guangxi, Shandong is relatively high, belong to the second echelon. Henan, Shaanxi, Chongqing, Hunan, Hubei, basically 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 and resource consuming industries, such as, machinery manufacturing, energy and resource development, chemical, metallurgy and building materials industries, etc., therefore, lead to excessive natural resources consumption; at the same time, saving resource mechanism is not perfect, which leads to the low resource efficiency. Sichuan, Yunnan, Hebei, Gansu, Xinjiang, Inner Mongolia, Guizhou basically belong to the fifth echelon. Total factor resource 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 resource output efficiency. Shanxi is a big province of coal production, consumption of coal and coke in industrial production is larger, while saving resource mechanism is not perfect, which leads to the low resource efficiency.

(2)Economic efficiency of resource. Economic efficiency of resource and total factor resource efficiency of the provincial regions showed basically a positive correlation. The regions of total factor resource efficient is high, correspondingly, economic efficiency of resource is relatively high. Beijing, Tianjin, Shanghai, Jiangsu, Zhejiang, Guangdong, Fujian, these provincial regions, relatively lack of resource, but economic efficiency of resource is the highest in China. The western region is rich in natural resources, while economic efficiency of resource is far lower than the eastern region. The region with abundant natural resources need avoid a single economic structure which dependend on excessivly 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 resource 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 resource. Most of the provincial regional environmental efficiency and eco-efficiency of resource is lower than the economic efficiency of resource. 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 ieda of ecological civilization, pay attention to economic growth and economic output, but underrate environmental protection. Regional environmental efficiency of resource closely related to total factor resource efficiency. Guangdong, Jiangsu, Hainan, Tianjin, Beijing, Shanghai, Guangxi, Zhejiang, Fujian, environmental efficiency of resource 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 resource 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.

Table 2 total factor resource efficiency,economic efficiency,environmental efficiency and eco-efficiency of resource of Chinese provincial regions in 2012

geographical district	provincial region	total factor resource efficiency	economic efficiency of resource	environmental efficiency of resource	eco-efficiency of resource
North China	Beijing	1.000	1.000	0.835	1.000
	Tianjin	1.000	1.000	0.840	1.000
	Hebei	0.752	0.748	0.629	0.681
	Shanxi	0.658	0.652	0.457	0.516
	Inner Mongolia	0.703	0.691	0.586	0.674
Northeast China	Heilongjiang	0.815	0.809	0.738	0.790
	Jilin	0.819	0.817	0.741	0.782
	Liaoning	0.807	0.804	0.749	0.763
East China	Shanghai	1.000	1.000	0.822	1.000
	Jiangsu	1.000	1.000	1.000	0.917
	Zhejiang	1.000	1.000	0.813	0.928
	Anhui	0.936	0.925	0.728	0.814
	Fujian	1.000	0.962	0.781	0.893
	Shandong	0.921	0.910	0.734	0.829
	Jiangxi	0.948	0.941	0.732	0.835
Central China	Henan	0.912	0.885	0.679	0.791
	Hubei	0.814	0.807	0.621	0.748
	Hunan	0.839	0.826	0.617	0.754
South China	Guangdong	1.000	1.000	1.000	0.933
	Guangxi	0.927	0.913	0.816	0.892
	Hainan	1.000	0.944	0.928	0.936
Southwest China	Chongqing	0.850	0.849	0.723	0.807
	Sichuan	0.781	0.772	0.642	0.753
	Guizhou	0.695	0.663	0.619	0.648
	Yunnan	0.742	0.731	0.704	0.729
	Tibet	0.619	0.612	0.598	0.610
Northwest China	Shaanxi	0.863	0.859	0.629	0.755
	Gansu	0.724	0.715	0.571	0.627
	Qinghai	0.638	0.627	0.506	0.561
	Ningxia	0.557	0.548	0.462	0.546
	Xinjiang	0.706	0.683	0.527	0.594

(4)Eco-efficiency of resource. Eco-efficiency of resource and environmental efficiency of resource is positive correlation. This shows that the ecological damage and environmental pollution often has great relevance: on the one hand, ecological damage in the process of natural resources development and utilization often leads to environmental pollution; on the other hand, pollution of the environment, often leads to ecosystem destruction which is original good. Therefore, China must strengthen ecological protection awareness, in the process of natural resources 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 natural resources which is ready to develop; for those natural 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 natural resources development and utilization.

5. Conclusions

This paper integrated systematically the method of MFA, DEA, and the evaluation method of eco-efficiency, contracted an assessment approach of total factor resource efficiency from the perspective of green growth; and gave an empirical study of total factor resource efficiency, economic efficiency of resource, environmental efficiency of resource, and eco-efficiency of resource, of Chinese provincial regions for the year 2012.

The total factor resource efficiency assessment approach of this paper contracted, is a more scientific and comprehensive approach of assessing resource efficiency which is in conformity with green growth theory. This approach not only has considerable theoretical significance, but also has considerable practical significance. It can be used to assess total factor resource efficiency, for a nation or region to enhance the overall utilization efficiency of natural resources, implement green growth pattern, construct ecological civilization society of resource-conserving, provide decision references and theory supports.

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References

[1]Pearce D. Measuring Resource Productivity—a Background Paper[R]. London: the Department of Trade and Industry and Green Alliance conference, 2001.

[2]Dahlström K,Ekins P.Eco-efficiency Trends in the UK Steel and Aluminum Industries: Differences between Resource Efficiency and Resource Productivity[J].Journal of Industrial Ecology,2005,9(4) p.171-188.

[3]Schandl H,West J.Resource Use and Resource Efficiency in the Asia-Pacific Region[J].Global Environmental Change,2010,20(4) p.636-647.

[4]Bleischwitz R. International Economics of Resource Productivity—Relevance, Measurement, Empirical Trends, Innovation, Resource Policies [J]. Int Econ Econ Policy, 2010(7) p.227-244.

[5]Bian Y W,Yang F.Resource and Environment Efficiency Analysis of Provinces in China:A DEA Approach Based on Shannon's Entropy[J].Energy Policy,2010,38(4) p.1909-1917.

[6]Strazza C,Borghi A D,Gallo M, Borghi M D. Resource productivity enhancement as means for promoting cleaner production: analysis of co-incineration in cement plants through a life cycle approach[J].Journal of Cleaner Production,2011,19(14) p.1615-1621.

[7]Ang F,Passel S V,Mathijs E.An aggregate resource efficiency perspective on sustainability: A Sustainable Value application to the EU-15 countries[J].Ecological Economics,2011,71, p.99-110.

[8]Guo T Y,He S J,Dong G P.Metropolitan resources efficiencies, change trends and causes in China

under the goal to build an international metropolis[J].Journal of Geographical Sciences,2011,21(4) p.746-756.

[9]Barrett J,Scott K.Link between climate change mitigation and resource efficiency: A UK case study[J].Global Environmental Change,2012,22(1) p.299-307.

[10]Delmas M A, Pekovic S.Resource Efficiency Strategies and Market Conditions [J].Long Range Planning, 2013, 46(9) p.1-15.

[11]Von Weizsäcker E U,Ayres R U.Boosting resource productivity: Creatingping-pong dynamics between resource productivity and resource prices[J].Environmental Innovation and Societal Transitions,2013,9 p.48-55.

[12]Samus T, Lang B, Rohn H.Assessing the natural resource use and the resource efficiency potential of the Desertec concept[J].Solar Energy,2013,87(1) p.176-183.

[13]Rosen M A.Assessing global resource utilization efficiency in the industrial sector [J].Science of the Total Environment, 2013,462 p.804-807.

[14]Yang S Y, Yang Q C, Qian Y.A composite efficiency metrics for evaluation of resource and energy utilization[J].Energy,2013,61(13) p.455-462.

[15]Brennan T J,Palmer K L.Energy efficiency resource standards:Economics and policy[J].Utilities Policy,2013,25 p.58-68.

[16]Hoang V N.Analysis of resource efficiency:A production frontier approach[J].Journal of Environmental Management,2014,137(6):128-136.

[17]Rohn H,Pastewski N,Lettenmeier M, Wiesen K,Bienge K.Resource efficiency potential of selected technologies,products and strategies[J].Science of the Total Environment, 2014,473 (2) p.32-35.

[18]Du J,Cook W D,Liang L,Zhu J.Fixed cost and resource allocation based on DEA cross-efficiency [J].European Journal of Operational Research,2014,235(1) p.206-214.

[19]Massarutto A.The long and winding road to resource efficiency-- An interdisciplinary perspective on extended producer responsibility[J].Resources, Conservation and Recycling, 2014,85 (4) p. 11-21.

[20]Figge F,Young W,Barkemeyer R. Sufficiency or efficiency to achieve lower resource consumption and emissions? The role of the rebound effect [J].Journal of Cleaner Production, 2014, 69 (8) p.216-224.