Evaluation of Circular Economy Efficiency in Eastern China

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Abstract. Based on the impact of undesired output and the recycling characteristics of circular economy, this paper reconstructed the evaluation index of circular economy efficiency of Chinese provinces and cities, took the data of 10 provinces and cities in eastern China from 2011 to 2017 as the research object, and analyzed the efficiency of circular economy in eastern China by using the data envelopment analysis model. Research results show that: (1) From 2011 to 2017, the average efficiency of circular economy in 10 provinces and cities in eastern China was low, with serious two-level differentiation. From 2011 to 2015, the average efficiency of circular economy in all provinces and cities showed a slow downward trend, slightly recovered in 2016, and slightly declined in 2017. (2) In 2017, the pure technical efficiency of eastern China is high, but the scale efficiency is low. Therefore, Eastern China should first improve the scale efficiency, and then improve the pure technical efficiency. (3) In 2017, Tianjin, Jiangsu, Guangdong and Hainan focused on improving their scale efficiency, while Hebei, Zhejiang, Fujian and Shandong need to improve their pure technical efficiency and scale efficiency at the same time.

Keywords: Eastern China; Efficiency of circular economy; Data envelopment analysis.

1. Introduction
In recent years, China's various provinces and cities began to promote green and renewable construction. In order to improve the efficiency of resource utilization, the green economic form which can effectively deal with the “three wastes” has become a new mode of development in China's different provinces and cities. However, how about the efficiency of circular economy in China? What are the differences and trends of circular economy in different provinces and cities? What are the causes of the inefficiency of circular economy?

Around the above problems, researchers took many studies on the measurement of circular economy efficiency from the perspective of ecological efficiency. Such as Hoffren¹¹ who use the method of ecological efficiency puts forward five different calculation formulas to study the efficiency of Finland's national circular economy. Based on the principles of “reduction”, “reuse” and “resource-based” of circular economy, the empirical study on the efficiency of circular economy in 30 major provinces and cities in China²²shows that there are obvious regional differences in the efficiency of circular economy in China. There are many problems about non DEA efficiency and diminishing returns on scale in most provinces, and there are different degrees of input redundancy and output deficiency in these provinces. In addition, Chi qi shui⁸found that there were significant differences in the efficiency of circular economy in Beijing. For more related researches, one can see⁹⁻¹³.
This paper finds that the current research mainly has the following deficiencies: First, there was little consideration on the impact of unexpected output. Second, some literatures ignored the recycling characteristics of general industrial solid waste in the construction of index system. Third, the research is mainly concentrated in China or some provinces and cities. But there was little literature on the efficiency of circular economy in the East of China which are the most rapid economic development region in China. Therefore, we select sulfur dioxide emissions as an unexpected output and consider the recycling characteristics in the circular economy. More specially, we analyse the circular economy efficiency of 10 provinces and cities in eastern China from 2011 to 2017. Furthermore, we explore the root cause of its low efficiency.

2. Methodology

2.1. Data Envelopment Analysis
Assuming that there are n decision making units (DMUs), each DMU has m inputs $x_{ij}$ ($i=1,\ldots,m$), and produces outputs $y_{rf}$ ($r=1,\ldots,s$), then the traditional CCR model\cite{14} which introduced by Charnes, Cooper and Rhodes can be expressed as:

$$\begin{align*}
\min \theta \\
\text{s.t.} \\
\sum_{j=1}^{n} \eta_j x_{ij} + s^-_i &= \theta x_{i0}, \quad i=1,2,\ldots,m, \\
\sum_{j=1}^{n} \eta_j y_{rf} - s^+_r &= y_{r0}, \quad r=1,2,\ldots,s, \\
\eta_j, s^-_i, s^+_r &\geq 0, \quad j=1,2,\ldots,n. 
\end{align*}$$

The optimal value obtained by the model is called technical efficiency. $s^-_i$ and $s^+_r$ represent the relaxation of inputs and outputs respectively. $\eta_j$ is the weight multiplier. If the optimal value of the model is $\theta^* = 1$, then the evaluated decision unit is DMU$_0$ is DEA weak effective. If the optimal value of the model is $\theta^* = 1$, and $s^-_i = 0$, $s^+_r = 0$, then the evaluated DMU$_0$ is DEA efficient. If $\theta^* < 1$, then the evaluated DMU$_0$ is invalid. It means that there are too many resources are used in the production process.

The above model is based on the assumption that the return on scale remains unchanged. If a constraint condition is added in formula (1), namely

$$\sum_{j=1}^{n} \eta_j = 1,$$

Then (1) is transformed into BCC model\cite{15} which introduced by Banker, Charnes and Cooper. It is an efficiency evaluation model under the assumption of variable scale returns.

2.2. Selection of Research Indicators and Data Processing
Based on the previous studies, we contribute to study the efficiency of circular economy in eastern China after the 12th Five Year Plan. The data of 10 provinces and cities in the eastern part of China are taken as the research objects, and a total of 70 groups of data from 2011 to 2017 are selected as the research samples.

Secondly, we establish the evaluation index system of circular economy efficiency in China.

(1) Input variables: It mainly includes energy consumption (Electricity consumption by Region) and fixed asset investment. In order to avoid the fact that there are few decision making units and data to construct a nearly smooth frontier, this paper takes all input and output data in the sample investigation period as a reference technology set for the current period. Therefore, taking 2010 as the base period, this paper uses the price index table of fixed assets in different regions to reduce the investment of fixed assets in eastern China.

(2) Output variable: considering the recycling characteristics of circular economy, the comprehensive utilization rate of general industrial solid waste is introduced into the output variable. Secondly, GDP
is the main target to measure the economic development of each region, which reflects the expected output of circular economy in eastern provinces and cities. In order to eliminate price interference, taking 2010 as the constant price, this paper uses GDP index to reduce the regional GDP. Finally, sulfur dioxide emission is chosen as the unexpected output. All the data required for the research samples can be obtained according to the China Statistical Year book from 2012 to 2018.

3. The Overall Gap and Trend of Circular Economy Efficiency in Eastern China

By using the input-oriented CCR model and BCC model, we can respectively calculate the technical efficiency, pure technical efficiency and scale efficiency of circular economy in eastern China from 2011 to 2017. The results are shown in Table 1, figure 1 and Figure 2.

Table 1. Efficiency of circular economy in eastern China from 2011 to 2017.

| Provinces  | 2011    | 2012    | 2013    | 2014    | 2015    | 2016    | 2017    | Mean value |
|------------|---------|---------|---------|---------|---------|---------|---------|------------|
| Beijing    | 1.000   | 1.000   | 0.984   | 0.995   | 0.981   | 1.000   | 1.000   | 0.994      |
| Tianjin    | 0.935   | 0.939   | 0.899   | 0.890   | 0.870   | 0.912   | 0.910   | 0.908      |
| Hebei      | 0.469   | 0.420   | 0.378   | 0.360   | 0.356   | 0.349   | 0.328   | 0.380      |
| Shanghai   | 1.000   | 0.976   | 0.923   | 0.939   | 0.898   | 0.956   | 1.000   | 0.956      |
| Jiangsu    | 0.614   | 0.554   | 0.519   | 0.526   | 0.519   | 0.513   | 0.522   | 0.538      |
| Zhejiang   | 0.659   | 0.574   | 0.510   | 0.464   | 0.457   | 0.462   | 0.463   | 0.513      |
| Fujian     | 0.601   | 0.598   | 0.566   | 0.533   | 0.532   | 0.535   | 0.543   | 0.558      |
| Shandong   | 0.631   | 0.618   | 0.582   | 0.570   | 0.467   | 0.448   | 0.444   | 0.537      |
| Guangdong  | 0.823   | 0.768   | 0.706   | 0.648   | 0.594   | 0.616   | 0.622   | 0.682      |
| Hainan     | 1.000   | 1.000   | 1.000   | 0.839   | 0.884   | 1.000   | 0.793   | 0.931      |
| Mean value | 0.773   | 0.745   | 0.707   | 0.676   | 0.656   | 0.679   | 0.663   | 0.700      |

It can be seen from table 1 and Figure 1 that the efficiency of circular economy in eastern China is quite different from 2011 to 2017. The two-level differentiation is serious. The maximum average value is 0.994, the minimum average value is 0.380, and the average value is 0.700. From 2011 to 2015, the average efficiency of circular economy in all provinces and cities showed a slow downward trend, slightly recovered in 2016, and slightly declined in 2017. This shows that although China has begun to attach importance to circular economy, the efficiency of circular economy in eastern provinces and cities of China is not high in the past seven years, which needs to be further improved. In the past seven years, none of the provinces and cities has maintained the optimal efficiency of 1.000. Among them, Beijing has been in the production front of circular economy for four years, and it is the municipality with the highest efficiency of circular economy in the East. followed by Shanghai. Although the efficiency of circular economy is only 1.000 in two years, the efficiency of circular economy in other years has been above 0.898, which makes the efficiency of circular economy in seven years high. Hebei's technical efficiency of circular economy is the lowest, with an average value of 0.38. Its efficiency of circular economy has been lower than 0.380 since 2013. The efficiency has been deteriorating year by year, which has seriously lowered the efficiency of circular economy in the eastern region.

From figure 1, the average efficiency of Beijing, Tianjin, Shanghai and Hainan are all in high coincidence, which makes the circular economy efficiency of these four provinces in the East to maintain the best. The main reason for the low average efficiency of circular economy in Hebei and Fujian is that the pure technical efficiency is too low. The scale efficiency of both is more than 0.800, which makes the gap between the technical efficiency and pure technical efficiency of these two provinces smaller. The low efficiency of circular economy in Jiangsu, Shandong and Guangdong is due to the low efficiency of scale. Accordingly, the pure technical efficiency of these three provinces is relatively high, especially in Jiangsu and Guangdong. The average of pure technical efficiency is 0.979, second only to Beijing. Zhejiang Province is in the double low area, so it should improve its scale efficiency and pure technical efficiency at the same time.
Figure 2 shows that between 2011 and 2016, the technical efficiency and pure technical efficiency of the circular economy in eastern China basically kept the same trend of change, showing a slow decline and then rise trend. In 2017, the gap between the technical efficiency and pure technical efficiency of the circular economy in eastern China became larger, mainly because the decline in scale efficiency in 2017 exceeded the rise in pure technical efficiency. As a result, the efficiency of circular economy in 2017 is slightly lower than that in 2016. The scale efficiency shows the periodic characteristics of slow decline in 2011-2014, slow rise in 2014-2016 and decline in 2017, but both the increase and decrease are very low. In addition, we can also find that the main reason for the low average value of technical efficiency in eastern China lies in the low pure technical efficiency from Figure 1 and Figure 2. The second reason is that scale efficiency does not reach the optimum.

4. Analysis on the Efficiency of Circular Economy in Eastern China in 2017
In order to analyze the current situation of circular economy in eastern China better, table 2 makes statistics on the efficiency of circular economy in eastern China in 2017.
Table 2. The efficiency of circular economy in eastern China in 2017

| Provinces     | technical efficiency | pure technical efficiency | Scale efficiency | Scale income |
|---------------|-----------------------|---------------------------|------------------|--------------|
| Beijing       | 1.000                 | 1.000                     | 1.000            | -            |
| Tianjin       | 0.910                 | 1.000                     | 0.910            | drs          |
| Hebei         | 0.328                 | 0.410                     | 0.800            | drs          |
| Shanghai      | 1.000                 | 1.000                     | 1.000            | -            |
| Jiangsu       | 0.522                 | 0.904                     | 0.513            | drs          |
| Zhejiang      | 0.463                 | 0.630                     | 0.863            | drs          |
| Fujian        | 0.543                 | 0.755                     | 0.588            | drs          |
| Shandong      | 0.444                 | 0.500                     | 0.622            | drs          |
| Guangdong     | 0.622                 | 1.000                     | 0.793            | irs          |
| Hainan        | 0.793                 | 1.000                     | 0.793            |             |
| Mean value    | 0.663                 | 0.870                     | 0.761            |             |

Note: - represents constant return on scale, DRS represents decreasing return on scale and IRS represents increasing return on scale.

4.1. Technical Efficiency Analysis of Circular Economy in Eastern China

It can be seen from table 2 that the average value of circular economy efficiency in eastern China is not high in 2017, with an average score of 0.663. The highest value is 1.000. The lowest value is 0.328. The distribution is extremely uneven with the standard deviation of 0.222. Only Beijing and Shanghai are technically effective among the 10 provinces, autonomous regions and municipalities directly under the central government in eastern China, with an efficiency value of 1.000, indicating that Beijing and Shanghai are still at the leading level in the development of circular economy in China. Among them, Tianjin is the only one with an efficiency value of 0.900-1.000, Hainan is 0.117 lower than Tianjin. Guangdong Province is the only one with an efficiency value of 0.600-0.700, two provinces with an efficiency value of 0.500-0.600, and the efficiency values of the other three provinces are below 0.500, which greatly reduces the average value of circular economic efficiency of eastern China.

4.2. Pure Technical Efficiency Analysis of Circular Economy in Eastern China

The pure technical efficiency of Tianjin, Jiangsu, Guangdong and Hainan has reached 1.000 besides Beijing and Shanghai, which shows that the pure technical efficiency of these four provinces and cities has reached the optimal state. But these four provinces and cities have not reached the optimal utilization in the input and output of circular economy. In addition, it can be seen from table 2 that Hebei's pure technical efficiency is the lowest, only 0.410, which is the root cause of Hebei's lowest technical efficiency. The situation in Fujian and Hebei is similar, because the pure technical efficiency is too low, the final technical efficiency is in a low position. Zhejiang's pure technical efficiency still has 9.6% room for improvement. Overall, the pure technical efficiency of eastern provinces and cities in China was in a leading position with 13% improvement space in 2017. The cities that need to be improved are Hebei, Fujian and Shandong.

4.3. Scale Efficiency Analysis of Circular Economy in Eastern China

The average of scale efficiency in eastern China is 0.761 which shows that there is a great room for improvement in resource utilization of circular economy in eastern China. The maximum value is 1.000 while the minimum value is 0.513 which means the two level differentiation is serious. Among them, the scale efficiency of other provinces and cities has a great gap except the scale efficiency of Beijing and Shanghai of 1.000. The scale efficiency of Zhejiang, Jiangsu and Shandong is lower than
0.600, which leads to low efficiency of circular economy in these three provinces. However, although the pure technical efficiency of Guangdong, Hainan and Tianjin has reached the optimal level in the eastern region, their scale efficiency is not good, which reduces the efficiency of circular economy in these provinces and cities. Through further analysis, it can be found that only Hainan Province is in the state of increasing returns to scale, so it can further increase the resource input of the province, and improve the efficiency by expanding the scale. While seven provinces and cities such as Tianjin and Hebei are in the state of decreasing returns to scale. Therefore, these provinces and cities should appropriately reduce resource input to keep it consistent with the optimal production scale.

5. Conclusion
In this paper, we use the CCR model and BCC model to analyse the efficiency of circular economy in eastern China from the perspectives of technical efficiency, pure technical efficiency and scale efficiency. Combined with the recycling characteristics of circular economy and the impact of unexpected output, this paper takes the sulfur dioxide emissions and the comprehensive utilization rate of general industrial solid waste into the evaluation index, and makes an in depth analysis on the circular economy efficiency of 10 provinces and cities in eastern China from 2011 to 2017. According to the empirical analysis, the following conclusions can be drawn:

(1)The overall mean value of circular economy efficiency of 10 provinces and cities in eastern China is not high during 2011 and 2017, and the two level differentiation is serious. From 2011 to 2015, the average efficiency of circular economy in all provinces and cities showed a slow downward trend, slightly recovered in 2016, and slightly declined in 2017. The fundamental reason lies in the low efficiency of scale and pure technology. Among them, Beijing and Shanghai have always been at the forefront in developing circular economy, but no province has always maintained the optimal efficiency in the past seven years. In Hebei, Zhejiang, Shandong, Jiangsu, Fujian and Guangdong, the efficiency of circular economy is relatively low and there is much room for improvement.

(2)The average pure technical efficiency of 10 provinces and cities in eastern China was 0.870 in 2017, and the pure technical efficiency of 6 provinces and cities was 1.000. This shows that the overall technical environment of eastern China is good, but the scale efficiency is low, so eastern China should first improve its scale efficiency, and then improve the pure technical efficiency.

(3)Tianjin, Jiangsu, Guangdong and Hainan focused on improving their scale efficiency, while Hebei, Zhejiang, Fujian and Shandong need to improve their pure technical efficiency and scale efficiency at the same time in 2017. Among them, Hebei and Fujian should strengthen their pure technical efficiency, while Zhejiang and Shandong should pay more attention to the improvement of scale efficiency. In addition to the need to expand the scale of Hainan Province to improve efficiency, other scale invalid provinces and cities are in the stage of diminishing returns to scale, so we should appropriately reduce resource investment.

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