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Research on Development Efficiency of Circular Economy of Silk Road Economic Belt: Based on Super Efficiency DEA Model

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Abstract: With the rapid development of economy and the increasing problems of resource consumption and environmental pollution, circular economy has been recognized as a new way to promote the development of economy, society, ecology and harmony. DEA is a nonparametric efficiency evaluation method. The super efficiency DEA model was used to measure the circular economy development efficiency of nine provinces and cities along the western Silk Road Economic Belt during 2016-2020. Results prove that there is a big difference in circular economy efficiency among regions along the belt. The DEA average efficiency of Shaanxi, Chongqing, Xinjiang, Yunnan and Guangxi are all effective, while the DEA of Ningxia, Gansu, Qinghai and Sichuan is non-effective. The DEA of Ningxia and Sichuan is limited by the development scale. The results also show that Xinjiang, Gansu and Qinghai have input redundancy and output insufficiency to a certain extent. Based on the empirical results, suggestions on how to improve the efficiency of circular economy along the Silk Road Economic Belt are put forward.

1. Introduction

The western region has always been a blind area of environmental regulation and a high incidence area of ecological fragility. The development of circular economy has been confronted with problems such as backward development stage, strong resource dependence, single financing channel, backward technology and imperfect legal system [1]. Therefore, it is an extremely difficult task to realize the rapid, healthy and sustainable development of the recycling economy in western China. The proposal of "Silk Road Economic Belt", a major strategic idea, provides a new opportunity for the development of recycling economy in western China.

According to the Vision and Actions for Jointly Building the Silk Road Economic Belt and the 21st Century Maritime Silk Road issued by the National Development and Reform Commission in March 2015, 18 Chinese provinces and some core cities have been included in the key development regions of the Belt and Road Initiative, while the Silk Road Economic Belt mainly involves the five regions in Northwest of China and the four regions in Southwest of China. They include Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang. Chongqing, Sichuan, Yunnan and Guangxi are nine regions [2].

Circular economy has attracted the attention of experts and scholars. Huang Yang et al. (2021) used the two-stage DEA method to evaluate the industrial eco-efficiency of 29 provincial regions in China, find out the regions with effective and ineffective DEA, further analyze the reasons and put forward suggestions to improve the industrial eco-efficiency of each region [3]. Wan Chengcheng et al. (2018) used DEA to calculate the development efficiency of agricultural circular economy in 31 provinces and cities, and analyzed the input-output efficiency of cities with relatively ineffective circular economy [4]. Wang Junling et al. used the DEA model to measure the comprehensive efficiency, scale efficiency and technical efficiency of the circular economy in China's iron and steel industry, and used the Malquist index method to measure the changes of the circular economy efficiency in iron and steel industry of China [5]. Jia Guozhu et al used the improved DEA model to measure the circular economic efficiency of 31 provinces and cities in our construction industry. The research results show that the recycling economic efficiency in the construction industry in our country has been increasing, and the scale efficiency gradually tends to the optimal [6].The previous research results are abundant, which has important reference value for the development of this paper. According to the existing studies, some scholars use the traditional DEA to measure the efficiency of circular economy in various regions. However, the super-efficiency DEA model can fill a vacancy. Besides, considering that there are few studies on the measurement of circular economy development efficiency. This paper uses the super-efficiency DEA model to analyze the circular economy development efficiency of 9 provinces and cities along the Silk Road Economic Belt.

2. Establishment of Research Methods and Models

The Data Envelopment Analysis (DEA) is a non-parametric efficiency evaluation method jointly proposed by American Charles, Cooper and Charnes, Cooper & Rhodes in 1978 [7]. Due to the characteristics of wide application scope and relatively simple principle, DEA has special advantages in analyzing the situation of more input and more output, so its application scope expands rapidly, involving education, agriculture, environment, macroeconomics, finance, taxation, medical and health care, sports and other fields [8].

2.1. The CCR Model

Suppose that there are decision making units (DMU) to be evaluated, and m inputs are used to produce p outputs. X_{ij} is the first j a decision-making unit the input index of input, Y_{rj} is the first j a the first r kinds of output indicators of decision making units of output. $X_{ij} \geq 0$, $Y_{rj} \geq 0$. The efficiency calculation problem of the KTH decision making unit can be converted into the following linear programming, whose dual programming is as follows [9]:

$$\min[\theta - \varepsilon(e^T S^- + e^T S^+)]$$

$$\text{s.t.} \begin{cases} \sum_{j=1}^{n} \lambda_j X_{ij} + S^- = \theta X_{ik} \\ \sum_{j=1}^{n} \lambda_j Y_{rj} - S^+ = Y_{rk} \\ \lambda_j \geq 0, j = 1, 2, \ldots, n \\ S^- \geq 0, S^+ \geq 0 \end{cases} \tag{1}$$

Where, ε is infinitesimal, S^- is the relaxation variable of the input index of each DMU, S^+ is the relaxation variable of the output index of each DMU, θ is the comprehensive technical efficiency, λ_j is the weight of the input and output variables, when$\theta = 1$, and$S^- = 0$,$S^+ = 0$, is called the DEA effective; When $\theta = 1$, and $S^- \neq 0$or$S^+ \neq 0$, the DMU is called weak DEA effective; at that time, When $\theta < 1$, the DEA was said to be invalid. Further introducing the

restriction conditions $\sum_{i=1}^{n}\lambda_i = 1$into the CCR model, the BCC model under the condition of "variable return to scale" can be constructed.

2.2. Super Efficient DEA Model

When using the traditional DEA model to evaluate the efficiency of DMU, the efficiency values of multiple DMU may be 1 at the same time, so it is difficult to further compare and analyze the effective DMU. Anderson and Petersen established the super efficiency DEA model in 1993, which makes the relatively efficient DMCS can compare the high and low efficiency values, so as to make up for this defect. Its basic idea is that when evaluating the KTH decision making unit, its input and output are replaced by the linear combination of input and output of other decision making units, and the KTH decision making unit is excluded [10]. The super efficiency DEA model is as follows:

$$\min[\theta - \varepsilon(e^T S^- + e^T S^+)]$$

$$\text{s.t.}\begin{cases}\sum_{j=1,j\neq k}^{n}\lambda_j X_{ij} + S^- = \theta X_{ik} \\ \sum_{j=1,j\neq k}^{n}\lambda_j Y_{rj} - S^+ = Y_{rk} \\ \lambda_j \geq 0, j = 1,2,\ldots,n \\ S^- \geq 0, S^+ \geq 0\end{cases} \tag{2}$$

The variables in the super efficiency DEA model have the same meaning as those in the CCR model, but the restriction condition is added on the basis of the CCR model, that is, the KTH evaluated decision making unit is removed from the reference set. In order to illustrate it more directly, the super efficiency DEA model is illustrated next.

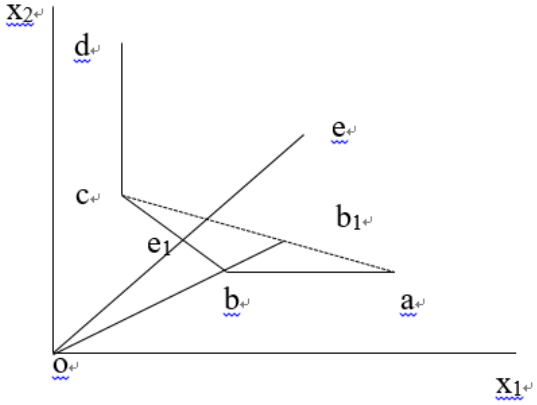

Figure 1: DEA diagram of super efficiency based on input orientation

In Figure 1, curve abcd is the effective production frontier, and points a, b, c and d are all DEA effective, while only point e is DEA ineffective. When the efficiency value of point b is calculated, it is excluded from the reference set, so the production front becomes acd, and the efficiency value of point b becomes $ob_1/ob>1$, that is, the super efficiency value of point b. Since point e was originally DEA invalid, its production front was still abcd, and the super efficiency evaluation value was consistent with the traditional DEA model, and the efficiency value was still $oe_1/oe<1$.

3. Selection of Decision Making Unit and Evaluation Index

Before using DEA method to measure the efficiency of circular economy of the Silk Road Economic Belt, systematic input and output indexes should be established. When selecting specific circular economy input index and output index, this paper referred to relevant domestic and foreign

research literature on circular economy evaluation system. Nine regions along the Silk Road Economic Belt were selected as decision-making units. The input-output indicators are shown in the table below. As can be seen from Table 1, an index system for evaluating the development efficiency of circular economy has been established.

Table 1: Evaluation index system of Input-output of circular economy of the Silk Road Economic Belt

First order index	Secondary index	units
Index of input	Energy consumption per unit of GDP X1	Tons of standard coal/Ten thousand yuan
	Power consumption per unit of GDP X2	Kilowatt hour/Ten thousand yuan
	Fixed asset investment as a share of GDP X3	One hundred million yuan
Index of output	GDP per capita Y1	yuan
	The proportion of value-added of tertiary industry in GDP Y2	%
	Garbage harmless disposal rate Y3	%
	Comprehensive utilization rate of industrial solid waste Y4	%

Considering the availability of data, input and output data for 2016-2020 are selected in this paper, mainly from China Statistical Yearbook, China Energy Statistical Yearbook and Tertiary Industry Statistical Yearbook.

4. Empirical Research

4. 1 SE-DEA Circular Economy Efficiency

The input-oriented super efficiency DEA model was used to measure the circular economy efficiency of each province and city, and MaxDEA software was used to calculate the super efficiency along the Silk Road Economic Belt from 2016 to 2020.

Table 2: Efficiency of circular economy development of nine regions during 2016-2020

District	2016	2017	2018	2019	2020	Mean	Ranking
Shaanxi	1. 099	1. 079	1. 119	1. 092	1. 096	1. 097	3
Gansu	0. 900	1. 003	0. 932	0. 848	0. 822	0. 901	8
Qinghai	0. 811	0. 874	0. 896	0. 773	0. 691	0. 809	9
Ningxia	0. 958	0. 972	0. 947	1. 019	0. 899	0. 959	7
Xinjiang	1. 026	1. 129	1. 153	0. 97	0. 847	1. 025	5
Chongqing	1. 551	1. 618	1. 586	1. 433	1. 567	1. 551	1
Sichuan	0. 964	0. 921	0. 995	0. 982	0. 953	0. 963	6
Yunnan	1. 069	0. 985	1. 061	1. 184	1. 051	1. 07	4
Guangxi	1. 139	1. 146	1. 129	1. 133	1. 143	1. 138	2
Mean	1. 057	1. 081	1. 091	1. 048	1. 008	1. 057	

As shown in Table 2, the efficiency of circular economy of the nine provinces and cities along the belt is relatively high from 2016 to 2020, and the average efficiency value is 1. 057. The average efficiency of Shaanxi, Yunnan, Chongqing, Guangxi and Xinjiang in the past five years have all reached DEA efficiency, and the circular economy efficiency values of Chongqing, Guangxi and Shaanxi are all greater than 1.The efficiency value of Chongqing ranks the first place, and its efficiency value in the past five years has outperformed other regions along the belt, this indicates

that the development of circular economy of Chongqing has paid full attention to the coordination of the whole system, and the effectiveness is optimal. The efficiency of Guangxi come second and showed a steady trend in the past five years. Shaanxi has a relatively stable development of circular economy, and the efficiency values over the years have all reached DEA effectiveness, indicating that input-output is optimized. In Yunnan Province, the efficiency was greater than one except that it was less than 1 in 2017, and the performance was effective. Efficiency of Xinjiang was the highest in 2018, continued to decline in the following two years, and reached the lowest in 2020, and DEA was ineffective. Although the circular economy efficiency value of Sichuan in recent years is less than one, the mean is 0. 963, which is approximate DEA efficiency, it indicates that the circular economy of Sichuan is developing well. The efficiency of Ningxia was greater than one in 2019, but was less than 1 in other years, and the DEA was also ineffective as a whole. The circular economy of Gansu showed a trend of first rising and then declining. The efficiency value in 2017 was greater than 1, and the DEA was invalid in other years. In the whole economic belt, the efficiency of circular economy in Qinghai region is the lowest, and the efficiency values of five years are all shown as invalid DEA, it indicates that Qinghai Province is still in the initial stage, resources are in short supply, so the efficiency value is low. In general, the overall efficiency value of the nine provinces and regions along the belt is high from 2016 to 2020, it indicates that these regions is developing well. For Qinghai and Gansu, which are relatively backward in development level, it is necessary to further increase the resources input and improve the efficiency of circular economy.

4.2. Efficiency Analysis of Circular Economy Development in Each Region along the Belt in 2020

In order to further understand the factors affecting the development efficiency, the indicators of each region in 2020 were analyzed. DEAP2. 1 was applied to calculate the TE, PTE and SE of 9 regions.

Table 3: Development efficiency and return to scale of circular economy in 2020

District	TE	PTE	SE	Returns to scale
Shaanxi	1.000	1.000	1.000	-
Gansu	0.822	0.830	0.991	irs
Qinghai	0.691	0.738	0.937	irs
Ningxia	0.899	1.000	0.899	drs
Xinjiang	0.847	0.898	0.943	irs
Chongqing	1.000	1.000	1.000	-
Sichuan	0.953	1.000	0.953	irs
Yunnan	1.000	1.000	1.000	-
Guangxi	1.000	1.000	1.000	-
Mean	0.913	0.941	0.969	

4.2.1. Technical Efficiency Analysis

As can be seen from Table 3, in 2020, there are 4 regions with DEA effective comprehensive technical efficiency, namely Shaanxi, Chongqing, Yunnan and Guangxi. Among them, the comprehensive technical efficiency of Gansu, Qinghai and Xinjiang is relatively low, mainly due to pure technical inefficiency and scale inefficiency, which to some extent reflects that these two regions are not sufficiently invested in power, energy resources, fixed assets investment and other aspects. It can also be seen that there is also a certain relationship between the development of

circular economy. They can obtain higher output and thus higher efficiency. The non-DEA efficiency of comprehensive technical efficiency in Ningxia and Sichuan is leaded by inefficiency of size. Therefore, the development of circular economy can be realized by expanding the development scale of circular economy or the level of resource allocation and management technology.

4.2.2. Pure Technical Efficiency Analysis

Pure technical efficiency refers to a certain output and minimum input consumption regardless of scale. It can be seen from Table 3 that in 2020, there are 6 regions where pure technical efficiency of circular economy reaches DEA effectiveness, respectively are Yunnan, Guangxi, Shaanxi, Ningxia, Sichuan and Chongqing. The pure technical efficiency of Gansu, Qinghai and Xinjiang is not high, and they are ineffective regions, which is also the reason for the low comprehensive technical efficiency of these regions.

4.2.3. Scale Efficiency Analysis

Table 3 shows that the average SE of circular economy in 2020 is 0. 969, it indicates that the SE of circular economy is high. There are 4 regions where SE reaches DEA effectiveness, they are Yunnan, Chongqing, Shaanxi and Guangxi. The scale efficiency of Ningxia, Gansu, Qinghai, Xinjiang and Sichuan was noneffective. From the perspective of return to scale, Qinghai, Gansu, Sichuan and Xinjiang are all growing, that is to say, if the input is increased, the output will grow at the same multiple higher than the input. Therefore, it can be achieved by increasing the input of resources and expanding the scale of circular economy development. Therefore, capital and energy play an important role, but attention should be paid to protect the environment. The diminishing returns to scale in Ningxia indicate that the current input resources are relatively sufficient. Even if the scale is further expanded, the output will not grow at the same multiple as the input. Therefore, attention should be paid to the allocation of resources and the utilization efficiency of circular economy to realize the further development of circular economy.

Table 4: Analysis of input-output relaxation variables in each region along the belt

District	The relaxation variable under variable returns to scale						
	S_1^-	S_2^-	S_3^-	S_1^+	S_2^+	S_3^+	S_4^+
Shaanxi	0. 000	0. 000	0. 000	0. 000	0. 000	0. 000	0. 000
Gansu	0. 061	0. 032	0. 000	3348. 788	0. 000	43. 951	0. 000
Qinghai	0. 530	0. 163	0. 000	0. 000	3. 432	3. 300	4. 409
Ningxia	0. 000	0. 000	0. 000	0. 000	0. 000	0. 000	0. 000
Xinjiang	0. 576	0. 060	0. 000	0. 000	0. 755	14. 496	10. 797
Chongqing	0. 000	0. 000	0. 000	0. 000	0. 000	0. 000	0. 000
Sichuan	0. 000	0. 000	0. 000	0. 000	0. 000	0. 000	0. 000
Yunnan	0. 000	0. 000	0. 000	0. 000	0. 000	0. 000	0. 000
Guangxi	0. 000	0. 000	0. 000	0. 000	0. 000	0. 000	0. 000

In the Table 4, the slack variable of scale under the variable remuneration of $S^-$and $S^+$of guangxi, shaanxi, sichuan, ningxia, yunnan and chongqing are all 0, showed no investment can reduce these areas, there is no need to increase the output, averaging the efficient use of energy and money, and obtained the maximum output. And gansu, qinghai and xinjiang $S^- \neq 0$ and$S^+ \neq 0$, namely, input redundancy and output deficiency. Next, the projection analysis is made for these three regions.

Table 5: Projection analysis of non-DEA effective regions

District	X1	X2	X3	Y1	Y2	Y3	Y4
Gansu	-4. 92%	-18. 18%		+15. 24%		+105. 45%	
Qinghai	-28. 47%	-51. 26%			+10. 40%	+3. 69%	+7. 94%
Ningxia	-36. 55%	-41. 38%			+2. 09%	+18. 41%	+20. 94%

Projection analysis is made on input-output of non-DEA effective regions, as shown in Table 5, Gansu, Qinghai and Xinjiang have certain redundancy in energy consumption per unit GDP and power consumption per unit GDP. If the output level remains unchanged, the energy consumption per unit of GDP and power consumption per unit of GDP in Gansu can be reduced by 4.92% and 18.18%, respectively. If the input structure needs to remain unchanged, the per capita GDP of Gansu should be increased by 15.24%, and the harmless treatment rate of household waste can be improved by as much as 105.45%. It can be seen that the energy utilization rate in Gansu province needs to be improved. In terms of economy, per capita GDP should be further increased. In terms of environment, the harmless treatment of household garbage needs to be solved urgently. Therefore, it should reduce environmental pollution. In order to achieve relative DEA efficiency, energy consumption per unit of GDP and power consumption per unit of GDP in Qinghai region should be decreased by 28.47% and 51.26% respectively, the proportion of tertiary industry added value in GDP should increases by 10.40%, the harmless treatment rate of household waste increases by 3.69%, and the utilization rate of industrial solid waste should be increased by 7.94%. It needs to reduce pollutant discharge and improve waste utilization. The situation in Xinjiang and Qinghai is similar, and the input and output need to be adjusted accordingly according to the projection results.

5. Conclusion

Based on the panel data of nine regions from 2016 to 2020, this paper calculates and analyzes the circular economy development efficiency of nine regions by using the super-efficiency DEA model, and conclusions and suggestions is below:

(1) The efficiency of circular economy of nine regions is relatively high, and the average comprehensive technical efficiency of Chongqing, Guangxi, Shaanxi, Yunnan and Xinjiang reaches DEA effectiveness; For Sichuan and Ningxia, where pure technical efficiency is effective but scale efficiency is ineffective, they should seize the opportunity of building the Silk Road Economic Belt, learning from high-performing regions, increase resource input and optimize resource allocation, actively attract domestic and foreign investment. As for Gansu, Qinghai and Xinjiang, they should take the initiative to learn from the regions with higher level of circular economy development, expand the development scale of circular economy.

(2) From the projection analysis of non-DEA effective regions, it can be seen that some regions need promote the technology development, and make new breakthroughs in energy conservation and emission reduction. The added value of the tertiary industry in Qinghai and Xinjiang is insufficient in GDP output. As a tertiary industry with low input, little pollution and quick results, Qinghai and Xinjiang should increase GDP input and further improve urban household waste treatment facilities. At the same time, it is necessary to increase the control of environmental pollution, reduce the discharge of pollutants, improve the utilization of waste.

(3) The application of super-efficiency DEA model can effectively distinguish the development levels among regions with circular economy development efficiency of 1, which cannot be distinguished by the traditional DEA model, and more scientifically distinguish the order of circular economy efficiency of each region, which provides a certain theoretical basis for improving the development of circular economy of the Silk Road Economic Belt.

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