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Performance Evaluation of Sewage Treatment Plant under Sustainable Development

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ABSTRACT. *This article takes 748 sewage treatment plants in the three regions of the East, Central and West of China as the research object. Based on the purpose of sustainable development of sewage treatment plant. Apply the undesired output model - SBM to measure the efficiency of these sewage treatment plants, and Based on the measured values, the efficiency of the sewage treatment plants in the three regions of eastern, central and western regions was compared. The sustainability of China's sewage treatment plants has the problem of unbalanced regional development. The comprehensive application of the SBM model evaluation method is scientific and reasonable in evaluating the efficiency of the sewage treatment plant. The results obtained can also reflect the spatial distribution of the efficiency of the wastewater treatment plant being evaluated. Provide reference for the sustainable development of the sewage treatment plant.*

KEYWORDS: *Sewage treatment plant, Evaluation of efficiency, SBM model, Sustainable development*

1. Introduction

Sustainable development refers to the development of meeting the needs of the contemporary people without sacrificing the interests of the next generation[1]. The sustainable development of sewage treatment plant is that the sewage treatment plant forms a healthy and healthy growth mechanism through the innovation of processing technology and the innovation of management activities. It increases steadily in economic benefit and enhances the processing ability, thus bringing good social benefits, resource and environmental benefits, alleviating the shortage of water resources and ensuring the contemporary people. And future generations' demand for water resources. By the end of 2013, 3513 sewage treatment plants had been built up, and the sewage treatment capacity was about 149 million / day, which led to the development of the whole sewage treatment industry. Due to the lack of funds, all aspects of the sewage treatment did not play the greatest value of low efficiency, resulting in a shutdown or "sun" situation. When the sewage treatment

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plant is built by the government, it is shelved and does not operate because of its lack of operational capacity. This is a serious waste to public resources. In addition, the sludge produced by a daily treatment plant of 100 thousand tons is increasing at a speed of not less than 100 tons per day. It can be seen that sludge has become a new source of pollution.

2 Literature review

There are few studies on sewage treatment plants in China. Some researchers have studied the evaluation of sewage treatment plants. Such as: Yang (2003) years proposed from the sewage treatment standard level, treatment amount and the improvement of the environment these aspects of the sewage treatment plant evaluation of the operation effect [2]. Buy (2012) [3], Liu (2014) [4] respectively estimate sewage treatment plant operation from sewage treatment efficiency index and sewage treatment plant operation effect index. Gao (2006) efficiency evaluation based on technical scale of sewage treatment plant [5]. The literature provides some reference for the evaluation of sewage treatment, but it ignores the effects of the sewage sludge as a new environmental pollution source and the study on the sustainable development of sewage treatment plant.

Based on the theory of sustainable development, the 748 sewage treatment plants in 2014 urban drainage Statistical Yearbook in China will be taken as the research object. The index of sludge water content is introduced to evaluate the sustainability of sewage treatment plants, so as to provide reference for the development of sewage treatment plants.

3 Research method

3.1 Definition of the theory of sustainability

Sustainability is an important indicator of sustainability. The sustainability of sewage treatment plants can be measured according to the efficiency of sewage treatment plants. This paper defines the sustainability of sewage treatment plants according to the efficiency of sewage treatment plants. The value of efficiency equals 1 is regarded as sustainable, and the efficiency value is in the interval [0.5,1), which is considered to be better sustainable. The efficiency value is below 0.5. So we can evaluate sustainability according to the size of efficiency.

3.2 Evaluation model of sewage treatment efficiency based on slack variable

During the operation of a sewage treatment plant, undesirable by-products such as "expected output" or "good output" are produced. These by-products are known as "undesired output" or "bad output", such as sludge, harmful solids, etc [6].

It is assumed that the production system has n decision making units. Each unit

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has m inputs. S1 expected outputs and S2 undesirable outputs.

Define the matrix X, Yg, Yb, respectively:

$$X = \begin{bmatrix} X_1 & X_2 & \cdots & X_n \end{bmatrix} \in R^{m*n}$$

$$Y^g = \begin{bmatrix} y_1^g & y_2^g & \cdots & y_n^g \end{bmatrix} \in R^{S_1 x_n}$$

$$Y^b = \begin{bmatrix} y_1^b & y_2^b & \cdots & y_n^b \end{bmatrix} \in R^{S_2 x_n}$$

Among then, x＞0, yg＞0, yb＞0,

The above set can be transformed into:

$$P = \left\{ \left(x, y^g, y^b \right) \middle| x \geq x\lambda, y^g \leq y^g \lambda, y^b \geq y^b \lambda, \lambda \geq 0 \right\} \quad (1)$$

Among it, $\lambda \in R^n$ is the weight vector. $\lambda > 0$ show that the reward of scale is constant, and abbreviated as CRS. If the equation satisfies simultaneously $\lambda > 0$ and $\sum \lambda > 0$, it means variable returns to scale, and abbreviated as VRS. If the result of CRS and VRS is different, the result of VRS should be chosen. Therefore, the analysis of environmental efficiency is based on the VRS hypothesis. $x \geq x\lambda$ means that the actual input is greater than the input of the production frontier. $y^g \leq y^g \lambda$ indicates that the actual undesirable output is greater than the undesirable output of the production front.

The traditional radial DEA model does not consider the effect of "relaxation variable" on the efficiency value, nor does it consider the technical changes that increase the expected output and reduce the undesired output at the same time, so that the efficiency value of the measurement is inaccurate or biased. To solve this problem, Tone (2001) proposed an environmental efficiency evaluation model based on input and output slack variables (Slack-Based Measure, referred to as SBM model). On this basis, he further proposed the SBM expansion model, thus realizing the evaluation of environmental efficiency under the condition of undesirable output (Tone, 2004). The SBM efficiency model of a particular decision making unit can be expressed as:

$$P^x = \min \frac{1 - \frac{1}{m} \sum_{i=1}^{m} \frac{S_i^-}{x_{io}}}{1 + \frac{1}{S_1 + S_2} \left(\sum_{r=1}^{S_1} \frac{S_r^g}{y_{r0}^g} + \sum_{r=1}^{S_2} \frac{S_r^b}{y_{r0}^b} \right)} \quad (2)$$

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$$S_t = \begin{cases} x_0 = x\lambda + S^- \\ y_o^g = Y^g\lambda - S^g \\ y_0^b = Y^b\lambda + S^b \\ S^- \geq 0, S^g \geq 0, S^b \geq 0, \lambda \geq 0 \end{cases}$$

Among them, The formula (2) is a SBM efficiency model based on the CRS hypothesis. S-, Sb, Sg respectively represent slack variables of input variables, expected outputs and undesirable outputs. The target function Px has been reduced in terms of S-, Sb, Sg. When $S^- = S^b = S^g = 0$, the function has the optimal solution.That is to say, $P^x = 1$ decision making units achieve full and effective goals. If $0 \prec P^x \prec 1$, it shows the loss of efficiency in decision making units, i.e. inefficiency. The corresponding improvement is made in input and output. The magnitude of this improvement is determined by the ratio of loose variables to their respective inputs and outputs. The rate of environmental invalidation can be divided into inefficiency and inefficiency.

The function of inefficiency is:

$$IE_x = \frac{1}{m}\sum_{i=1}^{m}\frac{S_i^-}{X_{i0}}, (\mathrm{i} = 1, 2, \cdots, \mathrm{m}) \tag{3}$$

The "good output" inefficiency function is:

$$IE_x = \frac{1}{S_1}\sum_{i=1}^{S_1}\frac{S_r^g}{Y_{ro}^g}, (r = 1, 2, \cdots, S_1) \tag{4}$$

The inefficiency function of "undesired output" is:

$$IE_b = \frac{1}{S_2}\sum_{i=1}^{S_2}\frac{S_r^b}{Y_{r1}^b}, (r = 1, 2, \cdots, S_2) \tag{5}$$

Formula (3) - (5), $\frac{S^-}{X_{i0}}$ indicates the proportion of decision making unit I item to be reduced. $\frac{1}{m}\sum_{i=1}^{m}\frac{S_i^-}{X_{i0}}$ indicates that all inputs of a decision making unit can reduce the average ratio. $\frac{1}{S_2}\sum_{i=1}^{S_2}\frac{S_r^b}{Y_{r0}^b}$ represents the average value of the expandable proportion of all desired outputs of decision making units.

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4. Variable selection and data sources

4.1 Source of input-output variable data

There are a large number of large sewage treatment plants in China. This paper can not count the data of each sewage treatment plant. Therefore, 748 main sewage treatment plants are selected as the object of research and analysis according to China's annual statistical yearbook of urban drainage in 2014. This paper divides the 748 sewage treatment plants into the eastern region (including Beijing, Tianjin, Hebei, Liaoning, Jiangsu, Shanghai, Fujian, Shandong, Guangdong, Hainan), and the central region (including Shanxi, Jilin, Heilongjiang, municipalities, municipalities, municipalities and municipalities), and the West (The three groups include Sichuan, Chongqing, Yunnan, Ningxia, Shaanxi and Xinjiang provinces and municipalities. Their input and output indexes were counted respectively.

4.2 variables selection

Based on the above literature research and data availability, this paper selects capital, input labor force and operation input energy of sewage treatment plants as input indicators. The most direct output is the amount of sewage treatment, and the amount of sewage treatment is an important index of the ranking of the capacity of sewage treatment. Therefore, this paper selects the sewage treatment as the output index. In addition, the precipitated impurities after sewage treatment will mix part of the water and measure the water content of sludge for the sludge. Therefore, the expected output is expressed in terms of the sewage treatment capacity of the sewage treatment plant, and the undesired output is reflected by the moisture content of the sludge.

Input assets: the work of the sewage treatment plant to build and purchase fixed assets and the costs associated with this and the various fixed assets and cash deposits invested in the operation.

Labor: the staffing of the sewage treatment plant of the employees can reflect the size of the sewage treatment plant, and it is also an important symbol of the scale of the sewage treatment plant.

Energy: the energy consumed in the process of sewage treatment. Including water, electricity and other energy inputs. It can reflect the level, composition and growth rate of energy consumption. It can reflect the energy consumption of the total resource input, and it can also reflect the energy saving of the plant. Therefore, energy input is also an important indicator to measure the sustainability of the wastewater treatment plant.

Sewage treatment quantity: the tonnage of effluent after treatment is the most direct output of sewage treatment plant, and the amount of sewage treatment is an important index of the ranking of sewage treatment capacity. Therefore, the sewage treatment quantity is selected as the output index.

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Sludge water content: the precipitated impurities after sewage treatment will mix part of the water, which is the negative output index of the sewage treatment plant.

Table 1 variables

Style	Variables Name	Variables features	Remark
Input index	Labor	Staffing of the sewage treatment plant	
	Assets	Various fixed assets and cash deposits	
	Energy	Energy consumed in the process of sewage treatment	
Output index	Sewage treatment quantity	Amount of effluent treated	Positive production
	Sludge water content	Ratio of water to water in precipitation	Negative output

Table 2 Input-output index statistics

variables		statistical indicators	Eastern Region	Central region	Western Region	Whole country
		Sample number	518	140	90	748
Input index	Assets	Max	681822	4600	3960	681822
		Min	0.016	2.00	0.890	0.016
		Average	1641.720	151.292	218.868	1191.564
		Standard deviation	29933.049	498.600	661.541	24920.657
	Labor	Max	574.724	544.597	579.254	579.254
		Min	5.576	8.041	5.454	5.454
		Average	62.637	45.985	58.446	59.016
		Standard deviation	75.877	76.236	94.254	78.642
	Energy	Max	96054400	2174605 0	34024960	96054400
		Min	47.46	160.60	38.00	38.00
		Average	4487008.87	2569011. 51	3660198.9 6	4028542.93
		Standard	7371638.54	3712763.	6222312.4	6740251.41

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		deviation		35	5	26
Output index	Sewage treatment quantity	Max	32850	11278.5	13263.188	32850
		Min	10.95	67.89	28.105	10.95
		Average	1833.522	1128.386	1503.303	1661.812
	Sewage treatment quantity	Standard deviation	2619.642	1689.241	2496.149	2472.420
	Sewage treatment quantity	Max	280	89.9	96	280
		Min	8	50	19.2	8
		Average	76.361	78.281	77.733	76.886
		Standard deviation	12.733	3.698	7.888	11.089

The eastern region and the western region are far below the national average, especially in the eastern region of the eastern region more than ten times more than the central and western regions. In terms of output indicators, the eastern part of the sewage treatment volume is higher than the national average level is also higher than the central and western regions, but the gap is not large. In terms of sludge water content, the eastern region also has low national average level, while the central and western regions are still higher than the average level, but the gap is not large. The three regions are basically flat.

5 Results and analysis

5.1 Evaluation results

In this paper, we use the SBM model of non expected output to calculate the efficiency of 748 sewage treatment plants in the 2014 urban drainage statistical yearbook. It got the efficiency evaluation table, see Table 3

Table 3 Good sustainability

Region	Ratio	Provinces	Number	Percentage of the country
East	40.57%	Beijing	1	1.45%
		Fujian	4	5.78%
		Guangdong	13	18.84%
		Hainan	2	2.90%
		Jiangsu	3	4.35%
		Liaoning	1	1.45%

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		Shandong	4	5.80%
Middle	31.89%	Guangxi	3	4.35%
		Henan	2	2.90%
		Heilongjiang	1	1.45%
		Hunan	9	13.04%
		Jilin	1	1.45%
		Jiangxi	2	2.90%
		Shanxi	4	5.80%
West	27.54%	Yunnan	11	15.94%
		Sichuan	5	7.25%
		Shaanxi	1	1.45%
		Xinjiang	2	2.90%

These provinces and municipalities with an efficiency of 1 have strong sustainability. The sustainability of the eastern region is significantly higher than that of the central and western regions. Among them, Guangdong, Hunan and Yunnan are all more sustainable than ten percent. Beijing, Liaoning, Heilongjiang, Jilin and Shaanxi accounted for less than two percent of the country, and these regions have reached a weak sustainability. However, in terms of the national scope, these municipalities have also met the requirements of sustainability, but sustainability remains to be improved.

5.2 Unsustainable result analysis

In table 4, this part of the efficiency value is between 1 and 0.5, and its hold is good. The proportion of the central region is much higher than the proportion of the eastern and western regions, which indicates that the central region is generally good in sustainability, and the sustainability of Jiangxi province is very prominent in the central region. The eastern part of Guangdong and the western part of Yunnan are also very good.

Table 4. Better sustainability

Region	Ratio	Provinces	Number	Percentage of the country
East	30.48%	Fujian	4	4.88%
		Guangdong	9	10.96%
		Hebei	3	3.66%
		Liaoning	2	2.44%

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		Shandong	7	8.54%
Middle	47.57%	Guangxi	1	1.22%
		Hunan	5	6.10%
		Henan	1	1.22%
		Heilongjiang	4	4.88%
		Jilin	1	1.22%
		Jiangxi	25	30.49%
		Shanxi	2	2.44%
West	21.95%	Shaanxi	3	3.66%
		Sichuan	1	1.22%
		Xinjiang	2	2.44%
		Yunnan	12	14.63%

In table 5, the efficiency of this part is less than 0.5, indicating that the capacity of sustainable development of the sewage treatment plants in some areas is weak. The proportion of the eastern region is very large, accounting for more than ninety percent of the country's proportion, of which Guangdong province of Shandong has the largest proportion, more than twenty percent, while Henan in Beijing is less than two percent. It can be seen that there is also a great gap between the provinces and cities within the same region.

Table 5. Weak sustainability

Region	Ratio	Provinces	Number	Percentage of the country
East	90.82%	Beijing	3	0.59%
		Fujian	42	8.21%
		Guangdong	120	23.44%
		Henan	6	1.17%
		Hebei	78	15.23%
		Jiangsu	59	11.52%
		Liaoning	36	7.03%
		Shandong	106	20.70%
		Shanghai	11	2.15%
		Tianjin	4	0.78%
Middle	4.30%	Shanxi	22	4.30%
West	4.88%	Yunnan	25	4.88%

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6. Conclusion

In the construction of the evaluation index system of input-output, the SBM model is used to construct an input-output analysis framework for urban sewage treatment plant, so as to scientifically and reasonably determine the structure of the evaluation index system, so as to avoid the subjective uncertainty and objective non basis of the index screening. As for the determination of the output index, the paper takes the water content of the sludge as an indicator of the output of a blessing, fully considering the environmental function of the sewage treatment plant, and pays more attention to the foundation of the long-term operation and development of the sewage treatment plant and the better undertaking of the environmental function, and the objective and in-depth evaluation of the performance of the sewage treatment plant in China. It will provide important reference for sustainable development of sewage in China.

Comparing the existing performance research methods of urban sewage treatment plants, the paper adopts the undesired output SBM model which can effectively eliminate the inherent defects of the traditional DEA model and ingeniously solve the negative external benefit output problem, making the efficiency evaluation result more in line with the reality in order to verify the efficiency evaluation of the none expected output SBM model. With regard to the rationality and superiority of the traditional DEA model, the comparison and analysis of the results of the efficiency calculation of 748 sewage treatment plants in China by using the unexpected output SBM model further proves that the unexpected output SBM model can reflect the essence of efficiency evaluation more, and the results of the evaluation are more scientific and reasonable.

Limited by the number of model evaluation indicators, the results of the evaluation can reflect the overall efficiency level of the overall evaluation object, and lack a systematic and detailed analysis on the global perspective, which needs further study.

According to the results of the above and nationwide comparison, this paper holds that the overall development situation of the sewage treatment plants in China is better, but in some parts the overall layout and reasonable planning are still lacking, and the internal resources allocation of the sewage treatment plant has not reached the reasonable requirements. Next, we hope to provide references for the construction and development of sewage treatment plants in China.

(1) Pay attention to the rational allocation of resources. Because of the late start of the construction of sewage treatment plant in China, it is in the stage of vigorous construction, while our country pays more and more attention to environmental management, and the amount of sewage treatment has risen sharply. Many sewage treatment plants in our country can't match the quantity and quality of sewage treatment. Although many sewage treatment plants have done a lot of investment and construction, our government has also provided strong support to the construction and operation of sewage treatment plants, but the construction of sewage treatment plants in our country is not reasonable. Planning, the allocation of resources is not reasonable. For example, the loss and operation of some sewage

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treatment plants. Therefore, the sewage treatment plant in China should first be reasonable and long-term planning before strengthening the construction. In this way, the operation ability and efficiency of the port will be matched, the reasonable input and output can be reached, and the comprehensive efficiency can be improved.

(2) Strengthen cooperation and promote good competition. The scale of sewage treatment plants in China is uneven and the gap between regions is large. Therefore, cooperation among different regions should be strengthened according to their own conditions, so as to improve their efficiency by improving their own technology and management level.

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