ISSN 1746-7233, England, UK
World Journal of Modelling and Simulation
Vol. 4 (2008) No. 1, pp. 35-43

An evaluation model based on data envelopment analysis and its application to county circular economy *

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(*Received February 10 2007, Accepted May 1 2007*)

Abstract. In this paper, the application of data envelopment analysis theory(DEA) in the evaluation of county circular economy is discussed. Based on DEA theory, we propose a solution with 8 operating steps to evaluate the development status of the county circular economy. Then, we collect a large number of index data to set up a inputs-outputs index system by expert interview and the documentary review methods. Thirdly, according to the DEA theory, we analyses the initial inputs-outputs data by C^2R model. At last, a case study, with a background of a city's development of circular economy from 1995 to 2005, is given. Then, some valuable information, such as the relative efficiency of DMU, is acquired. Therefore, the development status of county circular economy is indicated.

Keywords: DEA, C^2R model, circular economy, relative efficiency

1 Introduction

Data envelopment analysis (DEA) was developed in the late 1970s by Charnes, Cooper and Rhodes, as a relative performance efficiency measurement for activities involving multiple outputs[2]. That is, DEA evaluates how well a particular program or operation performs relative to other programs performing similar tasks. Such a relative evaluation is obtained via a DEA estimation of a single or scalar measurement of performance efficiency. This scalar measurement of efficiency ranges in value from zero (impossibly inefficient) to 1.0 (the unit under assessment is actually located on the relative efficiency frontier)[3]. Values in between zero and 1.0 import some information on how far off a frontier an investigated unit was. Thus a DEA efficiency value of 0.75 loosely indicates that the unit in question is only about 75% as efficient as those units which make up the relative best performance frontier[4, 5].

DEA utilizes a variant of linear programming to evaluate the effects of a set of input factors or influencing factors on a set of multiple output or outcome factors. In fact, DEA was originally developed as a means of handling the assessment of multiple output or outcome processes which other performance evaluation methods could not easily handle. This evaluation results in an individual scalar measure of performance efficiency being calculated by the DEA algorithm for each and every unit or operating system being evaluated. The resultant calculated relative efficiency measures, in turn, can be used in what may be called a second stage analysis via multivariate statistics. This later stage statistical analysis of the initial DEA results, allow examination of assorted influence factors which could have induced the variations in DEA values across the observation units.

As a management science alternative to more traditional econometric methods of productivity analysis, DEA has been particularly successful in public sector applications[6]. This is not surprising since multiple output processes are rather common, if not the norm, among public sector operations. DEA has been applied

* This research was supported by the National Science Foundation for Distinguished Young Scholars, P. R. China (Grant No. 70425005) and the Teaching and Research Award Program for Outstanding Young Teachers in Higher Education Institutions of MOE of P. R. China (Grant No. 20023834-3).

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in public sector operations as diverse as education, health care, natural resource management, public finance, and military operations. In all of these cases, DEA was chosen as the assessment approach due to a lack of any viable alternatives.

In this paper, we use the theory of data envelopment analysis to set up a model to evaluate the development status of county circular economy. Firstly, a large number of the indexes data reflecting the development status of county economy are collected, then we choose the typical and representative indexes from the indexes which reflect the development state of circular economy. Secondly, according to the DEA theory, the inputs-outputs evaluating index of the county circular economy is set up, then, we analyses the initial inputs-outputs dates by C^2R model, and we can judge the real development level of the county circular economy. At last, a real example study is given to test and verify the relative efficiency of the development level of the circular economy. Overall, this study provide a method from qualitative analysis to quantitative analysis and then from the quantitative analysis to qualitative analysis at last.

The rest of this paper is organized as follows. In section 2, we discuss some basic knowledge of the theory about data envelopment analysis and introduce the important value of the DEA theory in the field of evaluating county circular economy. In section 3, We propose the basic thinking that DEA theory is applied in the field of evaluation of county circular economy, which includes 8 concrete steps. In section 4, we set up the evaluation model of circular economy and apply this model to deal with the actual question about analysis of county circular economy planning. In this section, the DEA method is used to analyze the relative efficiency of the development level of circular economy from 1995 to 2005 in Jiangyou county, Sichuan province, P. R. China. Next, in section 5, we compare this paper with the others to explain the saving grace of this paper. The presentation of conclusion is in section 6.

2 Preliminary concepts

DEA is a new kind of systematic analytic method. In the frame of DEA, researchers adopt a programming method of mathematics to evaluate the output validity of DUM via the effective sample data observed. Decision-Making Unit (DMU) is a system, in this system, an activity or a dynamic system is regarded as the one with certain border, within this range, certain amounts of factors of production are put into the system, and certain amounts of outputs are acquired. In order to maximize the benefit of this activity or dynamic system, a series of decision needs to be made in this process. In other words, the output is the result of a series of decision, so such a system is known as DMU. Every DMU has the certain amounts of input factors and output factors, and during the process of transforming input factors to the output onesthe goal of the DMU is realized. For each DMU, if the following two conditions are met simultaneously, it means that the DMU's efficiency reaches one hundred percent[8]: (1) Under the condition of existing input factors, any type of output factors can't be increased, unless the other type of output factors are reduced at the same time; (2) In order to reach the existing output level, any type of input factors can't be reduced, unless the other type of input factors are increased at the same time. Overall, if a DMU is up to 100% of the efficiency, this DMU is considered efficient, and is regarded as the effective DMU.

3 Circular economy evaluation method

In our study, the county circular economy system with certain input-output in specific period is regarded as a DMU of DEA. In the DMU of county circular economy system, during the process of inputs being transformed into outputs, the county circular economy system goal of DMU is realized. Using the basic function of DEA, we evaluate the development capacity of county circular economy, on this basis, some valuable decision information is proposed, which is about the capacity building of circular economy and contributes to the prediction, making policy, coordinating and control of system[9]. Fig. 1 shows how the DEA method is applied to the study on the county circular economy system.

In our study, in order to evaluate the developed status of the county circular economy, we propose a feedback model with 8 steps based on the DEA theory.The algorithm step of DEA evaluation model on circular economy is showed in the Fig. 2 as follows.

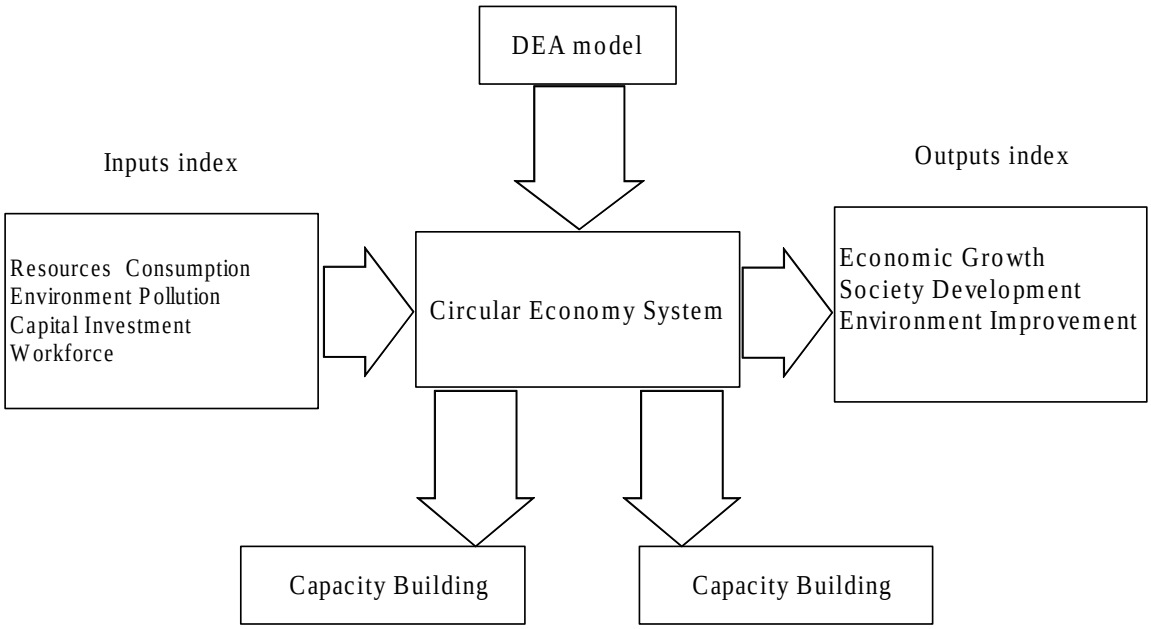

Fig. 1. Dea method applied to research on circular economy

3.1 Confirm the purpose of evaluation

The basic function of DEA method is evaluation, especially applied to evaluate the relatively advantage and relatively inferiority among a large number of similar samples[10]. In order to get the scientific evaluation conclusions and useful decision information via DEA method, we must analyses the concrete purpose of the evaluation task. It is the main basis of establishing the input-output index system and choosing the DEA model. In this paper, the DEA method is applied to evaluate the development status and the development capacity of county circular economy system. As to the whole system of the county circular economy, the stronger development capacity means that the system use the less resources consumption and the lower cost of environment loss to obtain the greater progress in economic growth society development and environment improvement[11]. Explained by the DEA theory, this process could be describe as this: to regard the resources consumption as the input factor of the circular economy system, and to regard the economic growth society development and environment improvement as the output factors, so the DEA's relative efficiency of county circular economy system is able to indicate the development capacity of the system.

3.2 Choose the DMU

To choose the Decision-Making Unit (DMU) means to determine the reference set. In technologically and experience, there are 2 conditions that indicate the relation between DEA and the number of DMU need to be met as follows: (1) The DMUs in the reference set should have the same type of characteristics; (2) In general, the number of the element in reference set should be no less than twice of the total number of the input-output index system[12]. In the study on evaluation of county circular economy, if we want to get the vertical contrast evaluation information about certain region, we should choose the different year or development period of this region as the DMU. On the contrary, if we want to get the horizontal contrast evaluation information among some different regions, we should pay attention to the DMU's comparative attribute among the different regions. In order to research the relative efficiency of DMU more scientifically, some ideal DMUs, which is some representative circular economy regions or the circular economy system with some concrete development goals, are added to the original sample DMUs. The surface efficiency phenomenon of DMU is overcome by adding the ideal DMUs, therefore, the task of analyzing the main factors that influenced the development of circular economy become more high-efficient.

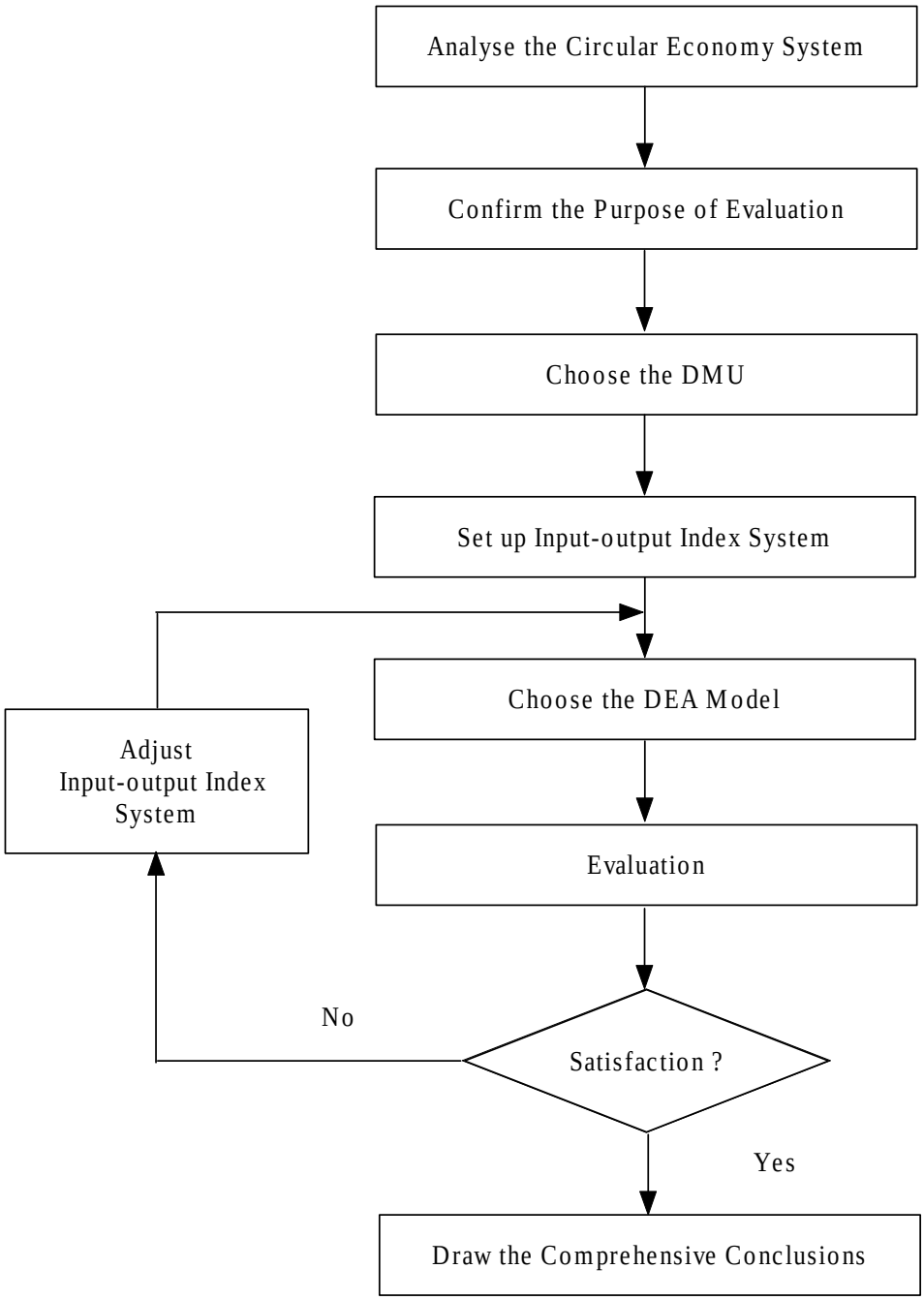

Fig. 2. The algorithm step of circular economy evaluation

3.3 Set up input-output index system

There are 3 principles to be followed in the task of setting up the input-output index system: (1) the chosen input-output index should indicate the goal of evaluation and the contents of evaluation; (2) the strong linear relevant relations among input-output indexes should be avoided in technically; (3) the variety of the index set should be considered. In the research of evaluation county circular economy, the input factors of the system include resources consumption, environment pollution, workforce, capital investment, and so on[13]. As well, the output factors of the system include economic growth, society development, environment improvement, and so on. But in some researches, it is indicated that the different evaluation result appears with the different input-output index. Therefore, the phenomenon of the evaluation result varying with the different index system should be paid attention to. In some researches, the compound DEA method is proposed, and via this method, the relation between the efficiency of DMU and the input-output system is acquired. Therefore, there is a wide

application prospects of the Compound DEA method applied to evaluate the development of county circular economy.

According to the analysis above, from the viewpoint of regional sustainable development, we structure the index system of circular economy evaluation, as follows Fig. 3.

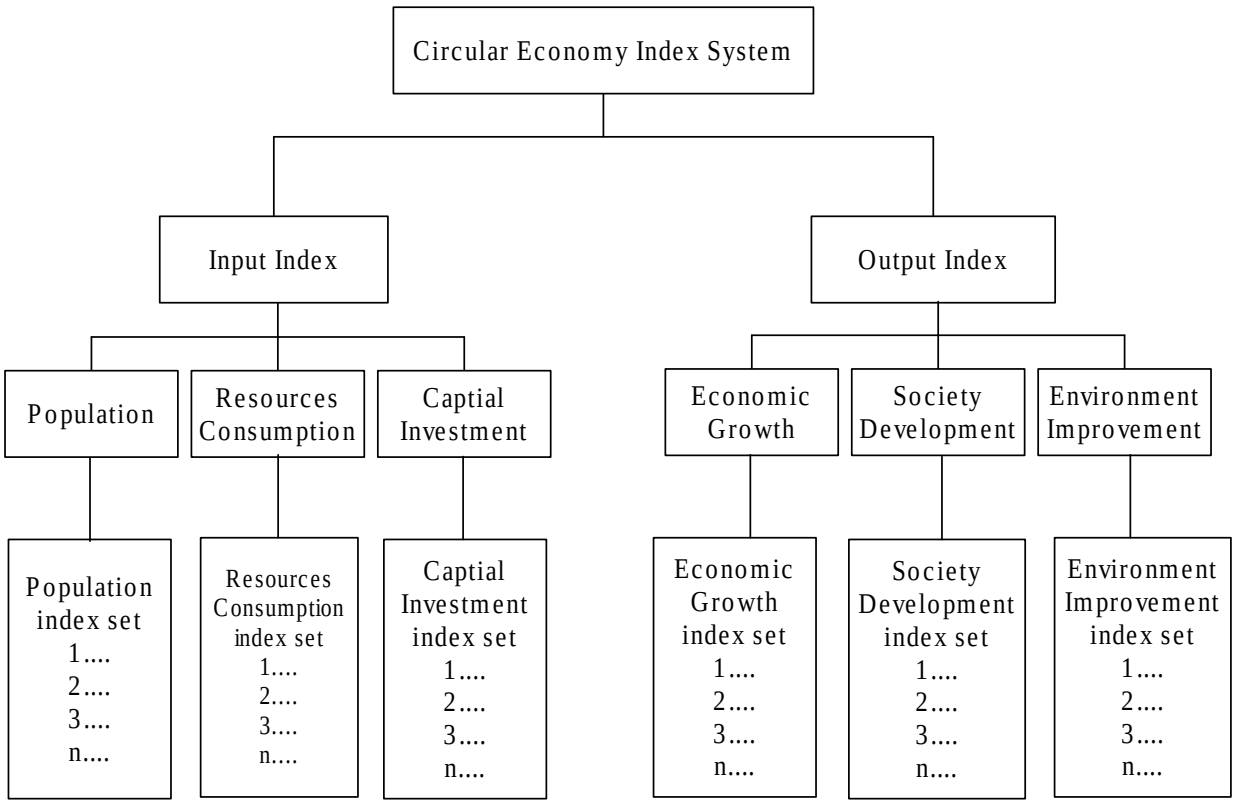

Fig. 3. Circular economy index system

3.4 Choose the DEA model and evaluation

The type of DEA model is various. Therefore, in actual research, we should choose the proper type of DEA models according to the different goals and different background of the research object. In the sample study of this paper, the C^2R model, which is applied to evaluate the scale efficiency and technological efficiency of EDA, is adopted.

In this step, the research object is evaluated via the chosen proper DEA model. The evaluation includes the following several parts: collecting and arranging the dates, calculating the DEA model, trial analysis by DEA model. According to the rationality of the evaluation result, if it is satisfactory, please go to the Step 8 to draw the comprehensive conclusions, otherwise, go to the Step 5 to adjust the input-output index system and to reelect a new model.

4 Application to county circular economy system

In this section, according to the DEA model above-mentioned, based on the C^2R model, a sample study about the application of DEA in the evaluation of county circular economy is given.

4.1 C^2R evaluation model

Every DMU has the certain amounts of input factors and output factors, and during the process of transforming input factors to the output onesthe goal of the DMU is realized. In order to evaluate the achieved degree of the goal of each DMU, we use the C^2R model to achieve the goal of our study. Using the C^2R model, we can evaluate the technological efficiency of DMU and the scale efficiency of the inputs of DMU at the same time. In C^2R model, the DMU with effective DEA is both the DMU with proper scale and the DMU with competent technical management.

Taking DMU k as an example, the C^2R model about DMU k is as follows:

$$\begin{cases} \max V_{kk} = \sum\limits_{r=1}^{s} u_{rk}y_{rk} / \sum\limits_{i=1}^{m} v_{ik}x_{ik}, & k = 1, 2, \cdots, n; \\ s.t. \sum\limits_{r=1}^{s} u_{rk}y_{rj} / \sum\limits_{i=1}^{m} v_{ik}x_{ij} \leq 1, & j = 1, 2, \cdots, n; \\ u_{1k}, u_{2k}, \cdots, u_{sk} \geq 0; v_{1k}, v_{2k}, \cdots, v_{mk} \geq 0 \end{cases} \tag{1}$$

u_{rk}—the weight of DMU k about the output criterion r.

v_{ik}—the weight of DMU k about the input criterion i.

It is a fractional equation programming model above-mentioned model (1), via the Charnes-Cooper Conversion, it is transformed to the following linear programming model:

$$\begin{cases} \max V_{kk} = \sum\limits_{r=1}^{s} u_{rk}y_{rk}, & k = 1, 2, \cdots, n; \\ s.t. \sum\limits_{r=1}^{s} u_{rk}y_{rj} - \sum\limits_{i=1}^{m} \omega_{ik}x_{ij} \leq 0, & j = 1, 2, \cdots, n; \\ \sum\limits_{i=1}^{m} \omega_{ik}x_{ik} = 1 \\ u_{1k}, u_{2k}, \cdots, u_{nk} \geq 0; \omega_{1k}, \omega_{2k}, \cdots, \omega_{mk} \geq 0 \end{cases} \tag{2}$$

u_{rk}—the weight of DMU k about the output criterion r.

ω_{ik}—the weight of DMU k about the input criterion i.

According to the DEA theory, the optimum value of the model (2) is equal to the optimum value of the model (1), therefore, the optimum value $maxV_{kk}$ of the model (1) is the supreme appraisal value of the relative efficiency of DMU k. When the value of $maxV_{kk}$ is 1, the DMU k is effective about DEA, otherwise, it is ineffective about DEA.

4.2 Index system

According to the analysis on index system above-mentioned, we set up a input-output index system which includes the following factors: population index set, economy index set, environment index set and society development index set. Tab. 1 shows this index system as follows:

4.3 Sample study

In this section, according to the DEA model above-mentioned, a sample study about the application of DEA in the evaluation of county circular economy is given. In this sample, the research object is the development status of Jiangyou county's circular economy from 1995 to 2005. The original data are gotten from the Statistical Yearbook of Jiangyou[14, 15]. Using the EMS software, we get the evaluation data of county circular economy which is showed in Tab. 2

In Tab. 2, X_1 denotes Total Volume of Social Employment. X_2 denotes Energy Consumption of GDP per—10,000 Yuan. X_3 denotes Total Investment of Environment Protection. X_4 denotes Total Investment in fixed Asset. X_5 denotes Per-capita GDP. X_6 denotes Disposable Income of Urbanite. X_7 denotes Per-capita Greenery Area of Urbanite. X_8 denotes Rate of Cycle Utilization of Industrial Water. X_9 denotes Rate of

Table 1. The input-output index system of the evaluating model

First Index System	Name of Index	Unit of Index
Population Index Set	Total Volume of Social Employment	10 000 Persons
Economy Index Set	Per-capita GDP	100 Million Yuan
	Total Investment in fixed Asset	100 Million Yuan
Environment Index Set	Energy Consumption of GDP per—10 000 Yuan	Ton. Standard Fuel Coal
	Volume of Sulphur Dioxide Emission	Ton
	Total Investment of Environment Protection	10 000 Yuan
	Rate of Cycle Utilization of Industrial Water	%
	Rate of Comprehensive Utilization of Solid Industrial Wastes	%
	Rate of Industrial Waste Water up to the Standards for Discharge	%
	Forest-coverage Rate	%
	Rate of Industrial Reused Water	%
	Per-capita Greenery Area of Urbanite	M^2/per-person
Society Development Index Set	Disposable Income of Urbanite	Yuan
	Per-capita Income of Peasant	Yuan

Table 2. Input-output data analysis

Year	DMU	Score	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
1995	DMU1	49.79%	0.02	0.00	0.00	53.57	0	0	7.58	7.58	7.58	7.58
1996	DMU2	74.24%	0.02	0.00	0.00	87.88	0	0	53.06	53.06	53.06	53.06
1997	DMU3	90.96%	0.02	0.00	0.00	1.40	0	0	1.54	1.54	1.54	1.54
1998	DMU4	100%	0.00	0.00	0.01	4.09	0	0	3.57	3.57	3.57	3.57
1999	DMU5	100%	0.00	0.04	0.00	1.35	0	0	1.17	1.17	1.17	1.17
2000	DMU6	100%	0.00	0.03	0.00	21.54	0	0	85.65	85.65	85.65	85.65
2001	DMU7	100%	0.00	0.04	0.00	64.92	0	0	61.72	61.72	61.72	61.72
2002	DMU8	99.94%	0.01	0.01	0.00	21.44	0	0	21.46	21.46	21.46	21.46
2003	DMU9	98.09%	0.01	0.01	0.00	2.15	0	0	2.19	2.19	2.19	2.19
2004	DMU10	100%	0.01	0.01	0.00	1.95	0	0	1.92	1.92	1.92	1.92
2005	DMU11	100%	0.02	0.00	0.00	0.57	0	0	0.50	0.50	0.50	0.50

Comprehensive Utilization of Solid Industrial Wastes. X_{10} denotes Volume of Sulphur Dioxide Emission. "Score" in Tab. 2 denotes the DEA efficiency value of DMU.

According to the data in Tab. 2, we get the evaluation result of the development status of Jiangyou's circular economy. The evaluation result is showed in Tab. 3.

Table 3. The dea comprehensive analysis

Year	Score	Relative Efficiency	Scale Efficiency	Technological Efficiency	Input-output Performance
1995	0.4979	DEA Ineffective	Increase Progressively	Ineffective	Improve
1996	0.7424	DEA Ineffective	Increase Progressively	Ineffective	Improve
1997	0.9069	DEA Ineffective	Increase Progressively	Ineffective	Improve
1998	1	DEA Effective	Proper	Effective	Improve
1999	1	DEA Effective	Proper	Effective	Constant
2000	1	DEA Effective	Proper	Effective	Constant
2001	1	DEA Effective	Proper	Effective	Constant
2002	0.9994	DEA Ineffective	Increase Progressively	Ineffective	Reduce
2003	0.9809	DEA Ineffective	Increase Progressively	Ineffective	Reduce
2004	1	DEA Effective	Proper	Effective	Improve
2005	1	DEA Effective	Proper	Effective	Constant

In Tab. 3, it is showed that the DMU of 1998, 1999, 2000, 2001, 2004 and 2005 is DEA effective, and the other DMU is DEA ineffective. In the DMU with DEA ineffective, the resources distribution don't reach

the optimally. Therefore, in order to improve the resources distribution efficiency of the DMU with DEA ineffective, we calculate the saved volume of input factors as follows Tab. 4.

Table 4. The dea comprehensive analysis

Year	Score	Saved Volume of Social Employment (10,000 Persons)	Saved Volume of Energy Consumption (Ton. Standard Fuel Coal)	Saved Volume of Investment in fixed Asset Consumption (100 Million Yuan)	Saved Volume of Investment of Environment Protection (10,000 Yuan)
1995	0.4979	26.63	148.95	3.52	2262.78
1996	0.7424	12.97	76.84	2.02	137.48
1997	0.9069	4.70	25.42	0.76	15.23
2002	0.9994	0.03	0.18	0.009	11.86
2003	0.9809	0.82	7.31	0.32	274.79

5 Compare and analysis

In the research of evaluating county circular economy, some paper are about ecological environment, some are about evaluating some industry, some are about evaluating technology of cleaner production and so on. But they are only one aspect of the county circular economy and they are unilateral and in single point of view. However, this paper adopts large amount of indexes and evaluates county circular economy in the integrate point of view. It is an innovation in the evaluating view. In this thesis, according to the basic thinking of DEA theory, we specify the evaluation index about circular economy while choosing the index system, and develops the input output index system that is specially applied the circular economy field. It is an innovation in the methodological layer. And this method is feasible which is tested by demonstration study.

6 Conclusion

In this paper, we use the evaluating model of DEA to make a study on county circular economy. By the DEA model, the evaluation result shows that the developed status of this county circular economy is between the good and the better, that is to say, the circular economy of this county need strength in order to arrive further goal. Through the analysis of the evaluating result, it can help the local government to establish the economical and societal and environmental policies and help the local government to plan the future stratagem about county circular economy. We also need to do further study on the evaluating county circular economy based on this paper, for example, we need to subdivide the index system which associates with the every aspect of county circular economy and we can get more accurate evaluating method and model to construct sustainability of the circular economy system.

References

[1] K. Yagi. Concept and Development of Ecomaterials. *Proceedings of the International Workshop on Ecomaterials*, 2002, 1-4.

[2] Y. Zhang, H. Qi, Research of the evaluation of sustainable development in Cuangzhou city based on NNA . *Preceeding of the Fifth International Conference on Machine Learning and Cybernetics*, DaLian, P. R. China, 2006, 13-16.

[3] J. Huisman, C. Boks, A. Stevels. The concept of describing product recyclability in terms of environmental value. *The International Journal of Production Research*, 2006, **41** (16): 3649-3665.

[4] J. Huisman, Quantifying recyclability and eco-efficiency for end-of-life treatment of consumer electronic products. *Delft University of Technology*, May 2003.

[5] http://www.emp.pdx.edu/dea/home/dea.html. *Data Envelopment Analysis (DEA) HomePage, Introduction to DEA [DB/OL],*

[6] R. Banker, A. Charnes, W. Cooper. Some models for estimating technical and scale inefficiencies in DEA. *Management Science* , 1984, **130** (9), 1078-1092.

[7] T. Coelli, D. Rao, G. Battese. An Introduction to Efficiency and Productivity Analysis. *Geographical Journal*, Kluwer, Dordrecht, The Netherlands, 1998.

[8] A. Bousstfnane, R. Dyson. Applied Data Envelopment Analysis. *Eumpean Journal of Operational Research 5*, 1991, 1-15.

[9] J. Sarkis, A methodological framework for evaluating environmentally conscious manufacturing programs. *Computers and Industrial Engineering*, 1999, (3) 29: 375-390.

[10] C. Simmons, K. Lewis, J. Barrett. Two feet two approaches: a component based model of ecological footprint. *Ecological Economics*, 2000, **332**: 375-380

[11] J. Doyle, R. Green, Efficiency and Cross-Efficiency in DEA Derivations, Meanings and Uses. *Journal of the Operational Research Society*, 1994, **(45)**: 567-578.

[12] T. Joro , P. Korhonen, J. Wallenius. Structural comparison of data envelopment analysis and multiple objective linear programming. *Management Science*, 1998,44, 962-970.

[13] G. Strassert. Physical input-output accounting and analysis: new perspectives. *13th International Conference on input-output Techniques*, 2000, 21-25 August, Macerata, Italy.

[14] National Bureau of Statistics of China, China Statistics Press. 2004-2005 (in Chinese).

[15] Statistic Bureau of Sichuan province, General Office of Sichuan Provincial People's Government, Sichuan Academy of Social Sciences, 1995-2005 (in Chinese).