Potential Analysis of Carbon Emission Reduction of China's Industrial Sector under the Requirements of Periodic Low Carbon Development

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Abstract—**Energy efficiency is used in the traditional DEA method as a reference standard when study the potential of carbon emission reduction. It ignores the fact there are periodic characteristics of the low-carbon development. The estimated emission reduction potential is difficult to fully release in the short term. So it can not be the basis of making the carbon emission reduction targets for China's industrial sector. However, the improved DEA model can freely choose reference to make judges. Therefore, this paper tries to use higher industry sector than any other low-carbon development stage of each industry as the low-carbon development standard, and compares and analyzes the carbon emission reduction potentials under the two methods. The results show that: Firstly, the overall level of low-carbon development of China's industrial sector in 2011 can be divided into five stages. The largest proportion is in the general stage of development of low-carbon industry, accounting for 36.8%; Secondly, the carbon reduction of vast majority of industries is lower under the phase of periodic reductions than the traditional method, the emission reduction decreases 8.1%;Thirdly, key industries of promoting the work of carbon emission reduction is the non-metallic mineral products industry, chemical raw materials, chemical products manufacturing, coal mining and washing industry, the key sectors is the mining industry.**

Index Terms—**All elements of energy efficiency, carbon emission potential, generalized DEA, periodic characteristic of low-carbon development.**

I. INTRODUCTION

Since the reform and opening up, China's economy has witnessed a rapid development and China has become the world's second largest economy. At the same time, energy consumption and CO_2 emissions are increasing. With the increasing awareness of environmental protection and sustainable development, energy-saving emission reduction has caused attention by more and more countries. China, as the largest emitter, faces a huge pressure to reduce carbon emissions. So at the 2009 Copenhagen climate conference, Chinese government officially announced the GDP carbon intensity will decrease by 40% -45% than that in 2005 by 2020. At the 2011 Durban climate conference, Chinese delegation further said that by 2015 the country Carbon

emissions intensity decreased by 17% compared with 2010. Industry, the most important emission sector has an important role in reducing carbon emissions. In 2014 the Ministry of Industry issued the "2014 main points of industrial energy-saving and comprehensive utilization" requires emissions of industrial companies decreases more than 4.5%. At the national level, the responsibility for carbon emission reduction will be broken down into each industrial sector. However, due to the imbalance of economic development and the heterogeneity of each industry, there still exist big differences in the commitment of carbon reduction targets and tasks. From the rational role of the broker, according to their economic characteristics, each industry sector will maximize their own interests to make most favorable carbon emissions aims for their own development. Therefore, how to develop differentiated carbon emission reduction targets and avoid cutting at one stroke in dealing with carbon emission reduction targets and undermining the enthusiasm of various sectors of carbon emissions reduction will become the focus of future research.

II. LITERATURE REVIEW

Since the 1970s, Europe, United States and other developed countries began to pay attention to energy-saving emission reduction work; pre-research focused on energy efficiency, less energy-saving emission reduction literature was related to potential analysis. Bojic *et al* started on energy saving and emission reduction concept research in early time [1]. Brend *et al* discussed on energy-saving emission reduction policies of developed countries, emphasizing the important role of government guidance [2]. On the basis of drawing foreign mature theory, Domestic scholars have done a lot of research in energy use, environmental protection and sustainable development. In recent years, the research on energy saving and emission reduction potential based on energy efficiency analysis has become a hot research topic in China. The DEA method in the framework of total factor productivity has overcome the shortcomings of single factor energy efficiency method. Related researches are developed from regional and industry aspects.

First, from a regional perspective, according to Qu's research, the total factor energy efficiency of the 30 provinces in China is quite different, and the industrial energy saving potential and energy saving scale of the central and western provinces are larger than those of the eastern region [3]. Wang *et al* found that from 2000 to 2007 China's overall energy efficiency level is low, three large regional has big energy

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saving potential [4]. Gao made study of carbon emission reduction potential of the six provinces in central China from 2000 to 2009 and found that carbon emission reduction potential has a decreasing trend year by year [5]. Second, from the point of industry, Zhou applied the DEA method to explore the energy efficiency differences of 39 industrial sectors in China from 2005 to 2010 and calculated the energy saving potentials of different industrial sectors and different factor density industries [6].

Yu made research of the 36 industries about energy efficiency and emissions reduction potential differences from 2000 to 2009 and found that there are significant differences in each industry and showed dynamic changes [7]. Zhang used input-output table to measure energy efficiency and energy input redundancy of 22 major industrial sectors from 2000-2009. The study found that most departments of energy efficiency is low and there is a lot of energy-saving space [8].

It often taken the best unit as the standard when DEA method is used to study the potential of energy saving and emission reduction. The potential value of energy saving and emission reduction is the theoretical value without consideration of actual conditions, although it has a certain significance, but it will make the feasibility of energy-saving emission reduction targets which only take the total energy efficiency as the optimal unit face a huge challenge. It is difficult to stimulate the enthusiasm of other energy-saving emission reduction method and achieve the desired energy-saving emission reduction targets.

Based on the study of the differences of energy efficiency of industrial sectors, the generalized DEA model is used to calculate the carbon emission reduction potential of each industry, only taking the higher industrial sector than the low carbon development in each industry as reference and make the practical periodic carbon reduction targets conformed to the efficiency principle.

III. MODEL AND VARIABLE DESCRIPTION

A. Generalized DEA Model

Data Envelopment Analysis (DEA) is an important method of evaluating relative efficiency proposed by the researchers Chares and Cooper [9]. When using the effective production frontier traditional DEA model to simulate the empirical production function in the traditional DEA model, the calculated efficiency value reflects the information of evaluation unit relative to the excellent unit, which to some extent limits the scope of people's research. In reality, the criteria for policymakers are not only this. In order to solve the problem that the "reference set" in traditional DEA model can only be "effective decision unit", Ma proposed the generalized DEA model, which extended the "reference set" to general decision unit, poor decision unit or some designated Unit[10]. Figure 1 reveals the differences between the two alternative evaluation reference sets from a more intuitive perspective.

Based on the purpose of the study, this paper chooses the generalized CCR model with constant returns to scale and measures the carbon emission reduction potential of the industrial sector under the periodic low carbon development. We assume that the decision maker has several decision units to evaluate, in which $x_i = (x_{1j}, x_{2j}, \cdots, x_{mj})^T$ and $y_j = (y_{1j}, y_{2j}, \cdots, y_{mj})^T$ stands for the decision-making unit of input and output indicators respectively. The decision maker selects m index to evaluate. Selecting several sample units (control group) as the basis for evaluating other decision units, so the input and output indicators of the j sample unit are $\overline{x}_j = (\overline{x}_{1j}, \overline{x}_{2j}, \cdots, \overline{x}_{mj})^T$ and $\overline{y}_j = (\overline{y}_{1j}, \overline{y}_{2j}, \cdots, \overline{y}_{mj})^T$.

Under the condition that satisfies the production possible axiomatic system [9], the reference set $T(1)$ can be expressed as:

$$T(1) = \left\{ (x,y) \middle| x \geq \sum_{j=1}^{\overline{n}} \overline{x}_j \lambda_j, y \leq \sum_{j=1}^{\overline{n}} \overline{y}_j \lambda_j, \delta \sum_{j=1}^{\overline{n}} \lambda_j = \delta, \lambda = (\lambda_1, \cdots \lambda_n) \geq 0 \right\} (1)$$

The generalized CCR model for decision making unit j_0 is:

$$(G-CCR) \begin{cases} \min \theta - \varepsilon \left(\hat{e}^T s^- + e^T s^+ \right) \\ s.t. \sum_{j=1}^{\overline{n}} \overline{x}_j \lambda_j + s^- = \theta x_{j0} \\ \sum_{j=1}^{\overline{n}} \overline{y}_j \lambda_j - s^+ = y_{j0} \\ \sum_{j=1}^{\overline{n}} \lambda_j = 1 \\ \lambda_j \geq 0, j = 1, 2, \cdots, \overline{n} \\ s^- \geq 0, s^+ \geq 0 \end{cases} (2)$$

ε is non-Archimedes infinitesimal, calculated by (2),the maximum potential of carbon emission reduction for each industrial sector is given by the following formula:

$$\begin{cases} \Delta x_{ij} = (1 - \theta^*) x_{ij} + s^- \\ ECERR_{ij} = \dfrac{(1 - \theta^*) x_{ij} + s^-}{x_{ij}} \\ i = 1; j = 1, 2, \cdots, 38 \end{cases} (3)$$

$x_{ij} (i = 1)$ in Formula (3) stands for CO_2 emissions from various industries; θ^* stands for the total factor energy efficiency; s_i^{-*} stands for the relaxation variable; Δx_{ij} stands for the carbon emission reduction; $ECERR_{ij}$ stands for emission reductions.

B. Input-output Variable Description

The data of 38 industrial sectors in China in 2011 are selected as the sample data. At the present stage, when we study the total factor energy efficiency, capital, labor and energy consumption are considered as the most important input factors of production. So this paper selects these three aspects as input indicators. Output indicators are industrial output value and CO_2 emissions, in which industrial output value is the expected output targets, CO_2 emissions is the non-expected output targets. Each input-output indicator is

defined as follows:

1) Capital investment: when estimating the capital stock, we use the perpetual inventory method. As the difficulty in obtaining the data needed by the industrial sector, the paper chooses the net value of fixed assets of each industrial sector according to Li's method[11] .The calculation method is the original value of fixed assets minus accumulated depreciation.

2) Labor input: the average working year of employees in the industry stands for the average annual labor input.

3) Energy input: the energy consumption of various industrial sectors converted to standard coal.

4) Expected Outputs: Considering the energy input of the intermediate input, the total output value of the intermediate inputs is chosen to represent the expected output.

5) Non-expected output: Using the CO_2 calculation method provided by IPCC, the terminal energy consumption will be multiplied by the emission coefficient, in order to reflect the energy consumption structure characteristics of different industries, choosing 16 kinds of energy consumption.

IV. EMPIRICAL ANALYSIS

A. Low-carbon Development Stage Division

The main methods for DEA model of dealing with undesired outputs are curve measure [12], direction distance function [13], input-output index change [14] and data transformation function processing [15]. With the improvement of the low-carbon capital market and the establishment of the carbon emission trading market and the carbon emission quota allocation system, CO_2 have become a special input cost in production, so the method chosen in this paper is to put CO_2 emissions into input processing. It will measure the low carbon development level of industrial department if the CO_2 can be included into total factor energy efficiency research, reflecting the periodic emission reduction responsibilities. This paper first calculates the total factor energy rate from high to low according to the traditional CCR model, and divides the 38 industrial sectors into high (1.0), high (0.8-1.0), medium (0.6-0.8), general (0.4-0.6), poor (less than 0.4) a total of 5 stages. The results are shown in Table I.

TABLE I: THE DIVISION OF LOW CARBON DEVELOPMENT STAGES IN CHINA'S INDUSTRIAL SECTOR

Industry	Efficiency value	Stage	Industry	Efficiency value	Stage
Tobacco Products Industry	1.000	High	Nonmetal Mining and Dressing	0.610	Medium
Leather, fur, feather (velvet) and other products	1.000	High	Food industry	0.591	Normal
Petroleum processing, coking and nuclear fuel processing	1.000	High	Textile industry	0.584	Normal
Communications equipment, computers and other electronic equipment	1.000	High	Smelting and Pressing of Ferrous Metals	0.552	Normal
Waste resources and waste materials recycling industry	1.000	High	Electricity, heat production and supply industry	0.546	Normal
Electrical machinery and equipment	0.959	Superior	Chemical fiber manufacturing	0.535	Normal
Instrumentation and cultural, office machinery	0.949	Superior	Pharmaceutical manufacturing	0.526	Normal
Furniture Manufacturing	0.935	Superior	Printing and recording media	0.522	Normal
Handicrafts and other manufacturing industries	0.890	Superior	Mining and Dressing of Ferrous Metals	0.521	Normal
Textiles and clothing, shoes, hats manufacturing	0.870	Superior	Nonferrous Metals Mining and Dressing	0.508	Normal
Agricultural food processing industry	0.846	Superior	Rubber products industry	0.492	Normal
Cultural, educational and sporting goods manufacturing industry	0.795	Medium	Beverage Manufacturing	0.491	Normal
Wood processing and wood, bamboo, rattan , grass	0.726	Medium	Chemical Raw Materials and Chemical Products	0.490	Normal
Transportation Equipment Manufacturing	0.699	Medium	Gas Production and Supply	0.463	Normal
Metal products industry	0.680	Medium	Non - metallic Mineral Products Industry	0.411	Normal
General Equipment Manufacturing	0.664	Medium	Paper and Paper Products	0.371	Worse
Smelting and Pressing of Nonferrous Metals	0.643	Medium	Petroleum and natural gas industries	0.335	Worse
Plastic products industry	0.633	Medium	Coal mining and washing industry	0.314	Worse
Special equipment manufacturing	0.618	Medium	Water production and supply	0.310	Worse

Note: The raw data is selected in the paper of China Statistical Yearbook 2012 and China Energy Statistical Yearbook 2012

From Table I, we can see from the industry point of view, in 2011 energy efficiency average of China's industrial sector is 0.660, the overall level is low and carbon emission reduction has huge potential. From the low-carbon development stage, there are only five sectors in the high-end industries, including the tobacco industry, leather, fur, feathers, petroleum processing, coking and nuclear fuel processing, communications equipment, computers and other electronic equipment, waste gas resources and waste materials recycling industry. However, paper and products industry, oil and gas mining industry, coal mining and washing industry, water production and supply industry are in the worse stage of low-carbon development, indicating that there is a large waste of energy and CO_2 emissions in these industries. The rate

difference between the highest energy efficiency sectors and the lowest is 0.69, showing that there are significant differences of energy efficiency levels between different industries. Therefore, it ignores the fact that there is a periodic characteristic of low-carbon development in various industries by using the unified standard of calculating emission reduction potential. So it can not be used as the basis for making emission reduction targets for various industries in China.

TABLE II: CONTRAST BETWEEN TRADITIONAL AND PERIODIC CARBON EMISSION REDUCTION POTENTIAL UNIT: 10^4

Department	Traditional periodic carbon emission reduction potential		Periodic carbon emission reduction potential	
	Emission reduction	Emission rate	Emission reduction	Emission rate
Coal mining and washing industry	12790.734	0.931	10337.572	0.752
Petroleum and natural gas industries	3183.230	0.713	3332.709	0.746
Mining and Dressing of Ferrous Metals	1083.507	0.799	631.639	0.466
Nonferrous Metals Mining and Dressing	225.708	0.574	90.079	0.229
Non-metal Mining and Dressing	870.872	0.874	756.385	0.759
Mining industry	18154.051	0.866	15148.384	0.723
Agricultural food processing industry	1196.930	0.454	1196.93	0.454
Food industry	1351.476	0.747	918.829	0.50
Beverage Manufacturing	1159.187	0.748	1006.113	0.650
Tobacco Products Industry	0.000	0.000	0.000	0.000
Textile industry	2068.987	0.660	561.530	0.179
Textiles and clothing, shoes, hats manufacturing	100.619	0.186	100.619	0.186
Leather, fur, feather (velvet) and its products industry	0.000	0.000	0.000	0.000
Wood processing and wood, bamboo, rattan, grass	582.813	0.665	320.996	0.36
Furniture Manufacturing	7.828	0.065	7.828	0.065
Paper Products	3865.636	0.903	2974.062	0.695
Printing and recording media	63.370	0.478	0.000	0.000
Cultural, educational and sporting goods manufacturing industry	16.840	0.205	7.787	0.095
Petroleum processing, coking and nuclear fuel processing	0.000	0.000	0.000	0.000
Chemical Raw Materials and Chemical Products	37156.026	0.946	30849.459	0.785
Pharmaceutical manufacturing	911.898	0.652	679.396	0.486
Chemical fiber manufacturing	441.002	0.653	0.000	0.000
Rubber products industry	621.448	0.722	508.188	0.591
Plastic products industry	286.204	0.367	191.753	0.246
Non - metallic Mineral Products Industry	43539.023	0.970	42276.475	0.942
Smelting and Pressing of Ferrous Metals	123656.469	0.982	0.000	0.000
Smelting and Pressing of Nonferrous Metals	4065.737	0.762	0.000	0.000
Metal products industry	357.500	0.320	207.337	0.185
General Equipment Manufacturing	2949.362	0.688	1818.049	0.424
Special equipment manufacturing	820.883	0.490	515.148	0.308
Transportation Equipment Manufacturing	776.839	0.301	0.000	0.00
Electrical machinery and equipment	32.750	0.041	32.750	0.041
Communications equipment, computers and other electronic equipment	0.000	0.000	0.000	0.000
Instrumentation and culture, office machinery	5.519	0.051	5.519	0.051
Handicrafts and other manufacturing industries	293.302	0.556	293.302	0.556
Waste resources and waste materials recycling industry	0.000	0.000	0.000	0.000
Manufacturing	226327.651	0.858	84472.069	0.320
Electricity, heat production and supply industry	2309.328	0.454	0.000	0.000
Gas Production and Supply	145.104	0.537	0.000	0.000
Water production and supply	45.456	0.690	25.348	0.385
Supply industry	2499.889	0.461	25.348	0.005

B. Analysis of Carbon Emission Reduction in Industrial Sector under Periodic Low Carbon Development

In terms of the differences of industry energy use efficiency and different characteristics of low-carbon industry development, we use different approach for the lower level industry group of low-carbon development stage and only select a higher level low-carbon development industry group as a reference set, then solve the industry's carbon emission reduction potential in this stage. This can avoid high carbon emission reduction targets caused by the carbon lock effect. At the same time, 38 industry sectors were classified into mining industry, manufacturing industry and supply industry according to the industrial classification method (DB / T4754-2002) and the actual research needs, so as to analyze the differences between three major categories of carbon emission reduction potential. In order to compare the difference between traditional and periodic carbon reduction potentials, this paper also lists the potential emission reductions calculated by the two methods. The result is seen on Table II.

In terms of the industry with zero emission reduction potential, the tobacco products industry, leather, fur, feathers and other products, petroleum processing, coking and nuclear fuel processing, communication equipment, computers and other electronic equipment, and waste material recycling industry is at the highest stage of low-carbon development, its emission reduction potential is zero both in periodic and in traditional mode. Under the periodic emission reduction requirements, printing and recording media replication, chemical fiber manufacturing, ferrous metal smelting and rolling processing industry, non-ferrous metal smelting and rolling processing industry, transportation equipment manufacturing, electricity and heat production and supply, gas production and supply industry were added to new industries of the emission reduction potential of 0. Due to the decline in the selected reference standard, the energy efficiency of these six industries reached the DEA effective. The potential for reducing emissions is a relative value, and the potential of zero emissions does not mean that the industry can not reduce emissions further, but there is little likelihood of further carbon reductions at the current optimal level of technology. On the other hand, this also means that the six sectors of the low-carbon development of the reference standards cannot meet its low-carbon development requirements, so we need learn from higher standards and develop their own industry development goals of carbon emissions.

In terms of reduction potential, electrical machinery and equipment manufacturing have the same emission reduction potential calculated in the two modes, because the selected reference set is under the higher carbon development stage. It also proves that traditional DEA method is a special form of general DEA model, which is an effective decision-making unit in the development stage of high and low carbon. However, the non-metallic mineral products industry, the chemical raw materials and chemical products manufacturing, coal mining and washing and dressing industries all have the highest emission reduction potentials in both modes, with emission reductions exceeding 100

million tons. Thus, reducing the emissions of these three sectors is the key to the management of industrial carbon emissions in China and should be targeted to help them to focus on support. The vast majority of industries in the periodic emission reduction requirements show a smaller the emission reductions, effectively reducing the pressure on carbon emissions, improving the industry's confidence and enthusiasm.

In terms of industry classification, the amount of emission reductions of mining, manufacturing and supply industry of emission reductions compared to the traditional way were reduced to varying degrees, including the manufacturing sector has the largest emission reduction, the rate goes down from 0.858 to 0.320, indicating that if considering the periodic development of low-carbon characteristics, the manufacturing industry can be reduced by 53.8%. Compared to the traditional way and periodic carbon emission reduction, the potential of the mining industry is the focus of the reduction of the industry. As such industries are resource-intensive industries and their low level of technical equipment, resulting in its low energy efficiency and a large number of emissions. The supply industry always has the smallest potential carbon emission reduction, lower than the manufacturing sector. Therefore, we still need to vigorously promote the work of carbon emission reduction in the manufacturing sector, focus on improving energy efficiency, releasing its emission reduction potential, and manufacturing is the basis for China's economic development, so we should adapt to change to green low carbon transformation.

V. Conclusion and Shortcoming

Based on the traditional DEA method, the non-expected output is included in the model, and the energy efficiency of the industrial sector in China is found. The results show that there are significant differences among different industries. Based on the above results, this paper adopts the periodic low-carbon development and adopts generalized DEA model to select the appropriate reference standard for low-carbon development of different industries, and estimates the carbon emission reduction potential of each industry under the new standard, compared with the carbon emission reduction potential measured by the traditional method. The main conclusions are as follows:

1) Take the established optimal production frontier as a reference; the level of low-carbon development of China's industrial sectors in 2011 can generally be divided into five stages, which five low carbon industries are in the high level, accounting for only 13.16%. There is significant energy efficiency and emission reduction potential gap between different industries, if a unified low-carbon development standards is required, the industry is bound to face a huge pressure on carbon emissions, hinder its normal development. Using the approach of gradual pushing, that is, a low-carbon development requirement above the level of industry groups as a standard can effectively reduce carbon emissions on the industry's economic development inhibition.

2) Compared with the traditional way of reducing emissions,

under the periodic emission reduction requirement, the industrial sector as a whole can reduce the 8.1% of carbon emission reduction. There is a significant reduction in carbon emissions in vast majority of industries, achieving the healthy development of the industry, taking into account the reality of various industries in different stages of development of low-carbon and fully reserve development space to determine CO_2 control.

3) Carbon emission reduction targets should be concentrated in the non-metallic mineral products industry, chemical raw materials and chemical products manufacturing, coal mining and washing industry. Under the requirement of periodic emission reduction, if fully release carbon emission reduction potential of these three industries, the overall contribution rate to the reduction of China's industrial was 28.77%. At the same time, the mining industry is a serious ineffective energy consumption sector, a huge role for the overall industrial emissions.

This study takes into account the characteristics of low-carbon development in various industries, which is of great significance to the study of carbon emission reduction potential in relatively complex industrial sectors. However, there are many factors for the emission reduction of industry sectors, faced with changing conditions from outside including policy, market and other aspects of the constraints. We still need to make division of standards, the choice of benchmarking industry, as well as industry heterogeneity refinement and other aspects of further research in the industry of low-carbon development stage and develop realistic, more scientific carbon emission reduction targets.

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