

# Study on the Liability-Sharing of Carbon Emissions in Cities of Hebei Province Based on DEA Model

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**Abstract**—Based on the decomposition of the overall national carbon reduction targets to municipalities, Hebei Province, sharing responsibility for carbon emissions. In this paper, prefectural-level city in Hebei Province as an example, use of undesirable outputs that carbon emissions as model inputs, the population, energy consumption and GDP as a model output variable. In accordance with the characteristics of the development of economy and society in Hebei Province forecasts the input and output data, using input-oriented DEA model to evaluate the efficiency and economic of the responsibility for carbon emission of 11 cities in Hebei Province in 2015, and based on the evaluation results gives suggestions to the cities for improvement. Proved that during the reduction process it has possibility to achieve economic development, it provides a reference to prefectural-level city in Hebei province for developing low-carbon economy.

**Keywords**—data envelopment analysis; carbon emissions; hebei Province; prefecture-level cities

## I. INTRODUCTION

As global temperatures rise, reduce greenhouse gas emissions has become a global consensus. The international community has undertaken a number of positive measures. From December 1997 in Kyoto, Japan, passed the world's first prescribed a quantitative greenhouse gas reduction obligations under the "Kyoto Protocol", to the December 2007 adopted the "Bali roadmap", proposed different requirements for developed and developing countries mitigate carbon emissions; On the meeting which was held in Copenhagen December 2009, China gave a commitment that in 2020 our carbon intensity decreased by 40 to 45% compared to 2005. By the end of 2011, in the climate conference in Durban, the representative of China said that, the Chinese government decided to greatly reduced the carbon intensity within five years, by 2015 the country carbon emissions intensity decreased by 17% compared to 2010, China is facing an increasingly powerful pressure to reduce emissions. In order to achieve these goals, we must break down the carbon emission reduction targets to various provinces, cities and even smaller economic unit of society, formulate regional low-carbon development goals and metrics, to clarify its carbon reduction responsibilities.

Regard to the apportion of carbon emissions responsibility, domestic and foreign scholars have conducted a wide range of related research. Lin Tan, Ning Junfei<sup>[1]</sup> studied the allocation efficiency of the European Union carbon emission rights, using

zero and DEA model, at the national level. Zheng Liquan<sup>[2]</sup> apportioned responsibility for carbon emissions of China's provinces and autonomous regions, break down the country's overall carbon reduction targets to the provinces. Wang Zhen and Zhao Dingtao<sup>[3]</sup>, based on the perspective of producers and consumers environmental liability, established a regional carbon emissions burden sharing model. Xu Yingzhi and Zhang Yun<sup>[4]</sup>, for the "carbon leakage" problems arising between regional trade, using multi-regional trade input-output model in the framework of inter-regional, analyzed carbon emissions responsibility of each region and the differences of carbon emissions responsibility in different industries. Taking these studies can find that energy consumption is a major source of carbon emissions, but research on energy carbon emissions almost concentrated at the national scale, relatively few studies on the provincial and municipal scale, and specific value of energy carbon emissions also failed to clear, therefore, carbon emissions needs further detailed study on the municipal level.

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## II. THEORETICAL BASIS AND THEORETICAL MODELS

Data envelopment analysis is a non-parametric programming units relative effectiveness evaluation method proposed by A.Charnes Operations Research famous American family and WWCooper other scholars based on "relative efficiency" concept and multi-input and multi-output index, to exclude a lot of subjective factors, with strong objectivity[5]. The core idea of DEA model is to use input-output data output projected maximum or minimum investment boundaries. It not only can assess and sort the relative effectiveness of each sort of decision making units of the same type, but also can analysis each of non-DEA effective decision-making unit causes and improve the direction, provide important information for the management decision makers [6].

Assuming a evaluation system with N of decision making units of the same type (DMU), each decision unit has m kinds of inputs and s kinds of outputs, establish the relative

efficiency of the decision-making unit evaluation BCC model is as follows:

$$\begin{cases} \min[\theta - \varepsilon(e_1^T s^- + e_2^T s^+)] = \theta^* \\ \sum_{j=1}^n \lambda_j X_{ij} + s_i^- = \theta X_0 \\ \sum_{j=1}^n \lambda_j X_{ij} - s_i^+ = Y_0 \\ \sum_{j=1}^n \lambda_j = 1, \lambda_j \geq 0, j = 1, \dots, n \\ \theta(\text{Unconstrained}), s^+ \geq 0, s^- \geq 0 \end{cases} \quad (1)$$

Formula(1):  $\theta$  is the relative efficiency;  $\square$  is the non-archimedean infinitesimal;  $e_1$  is m-dimensional unit vector;  $s^- = [s_1^-, s_2^-, \dots, s_s^-]$  is the difference vector of input;  $e_2$  is the s-dimensional unit column vector;  $s^+ = [s_1^+, s_2^+, \dots, s_s^+]$  is the difference vector of output;  $\theta^*$  is the relative efficiency target; n is the number of DMU need to evaluate;  $\lambda_j(j=1, 2, \dots, n)$  is the weight of right combination of DMU;  $X_{ij}$  is the i-th input of the j-th DMU;  $X_j$  is the input of the j-th DMU;  $X_j = [X_{1j}, X_{2j}, \dots, X_{mj}]$ ;  $i=1, 2, \dots, m$ ;  $X_0$  is the inputs of the DMU intend to assess;  $Y_{ij}$  is the i-th output of the j-th DMU;  $Y_j$  is the output of the j-th DMU;  $\lambda_0, s_0^-, s_0^+, \theta^0$  are the optimal solution of the C<sup>2</sup>R model.

### III. INDICATOR SELECTION AND PROCESSING OF DATA SOURCES

This article refers to the method proposed by Lins and Gomes[7], the population, GDP and energy consumption as the amount of output variables, the carbon emissions as the only input variables in the model. GDP is the desired output, Carbon dioxide emissions as undesirable output, currently, when dealing with undesirable output, the main method of DEA model is input method. Countdown conversion method, hyperbolic method, convert vector method, Directional distance function method, SBM model method, etc[8][9]. Since other methods may have the problem of no effective solutions, therefore, this article make undesirable outputs as inputs to deal with carbon emissions. Various data sources and processes as follows:

#### A. Calculate the Actual Carbon Emissions of Every City.

Using the Kaya formula proposed by a Japanese scholar Mao Yang Professor(Kaya Yoichi).

$$C = P \times (GDP / P) \times (E / GDP) \times (C / E) \quad (2)$$

Note: C-Carbon emissions; P-Population; E-Energy Consumption; GDP/P-GDP of per capita; E/GDP-Energy intensity, that is energy consumption per unit of GDP; C/E-Carbon emission factor. 0.6799tCO<sub>2</sub>/tce.

B. Based on the GDP data of each city from 2008 to 2012 from "Hebei Province Statistical Yearbook," using the average

growth rate method to forecast the GDP data of each city in 2015. As show in the TABLE I below.

C. Based on the population data of each city from 2008 to 2012 from "Hebei Province Statistical Yearbook," using the average growth rate method to forecast the population data of each city in 2015. As show in the TABLE I below.

D. Using heat consumption law The input data of Energy consumption directly use heat consumption law to translated a variety of energy into a unified total. The data from "Hebei Province Statistical Yearbook" in the calendar year. According to Energy/GDP elasticity, can calculate the total energy consumption in each city in 2015. As show in TABLE I below.

E. According to the formula (2) can predicted the actual carbon emissions of each city in Hebei Province in 2015 as show in the TABLE I below.

F. The input-output data of DEA model are shown in TABLE II.

TABLE I. EACH FORECAST DATA OF EACH CITY IN HEBEI PROVINCE IN 2015

City	Population (Ten thousand)	Energy Consumption Per Unit Of GDP (tce/Ten thousand yuan)	GDP (One hundred million yuan)	Total Energy Consumption (Ten thousand tons standard coal)	Carbon Emissions (Ten thousand tons)
SJZ	1075.1	0.879	7423.0	6524.87	4760.8
CD	357.0	0.810	2395.9	1940.70	1446.5
ZJK	450.7	0.954	2139.8	2041.39	1516.9
QHD	309.3	0.664	1904.2	1264.40	883.82
TS	788.2	1.289	10635	13709.5	9982.9
LF	464.8	2.138	3091.0	6608.64	4839.4
BD	1164.8	1.133	4341.4	4918.91	3438.3
CZ	744.6	2.003	4705.2	9424.70	6937.8
HS	446.2	1.850	1395.3	2581.45	1804.4
XT	740.1	1.237	2369.4	2930.95	2048.7
HD	964.68	1.064	5213.5	5547.26	4077.5

Note: SJZ is in the name of Shijiazhuang, CD is in the name of Chengde, ZJK is in the name of Zhangjiakou, QHD is in the name of Qinhuangdao, TS is in the name of Tangshan, LF is in the name of Langfang, BD is in the name of Baoding, CZ is in the name of Cangzhou, HS is in the name of Hengshui, XT is in the name of Xingtai, HD is in the name of Handan.

TABLE II. INPUT-OUTPUT CONDITIONS

City	Input Indicators	Output Indicators		
	Carbon emissions (Ten thousand tons)	Population (Ten thousand)	GDP (One hundred million yuan)	Energy Consumption (Ten thousand tons standard coal)
SJZ	4760.88	1075.19	7423.06	6121.09
CD	1446.55	357.08	2395.93	1500.83
ZJK	1516.93	450.78	2139.82	1835.56
QHD	883.82	309.33	1904.22	1119.78
TS	9982.99	788.25	10635.82	12395.06
LF	4839.44	464.88	3091.04	6132.19
BD	3438.32	1164.89	4341.49	5251.01
CZ	6937.86	744.64	4705.29	9638.91
HS	1804.44	446.25	1395.38	3092.30
XT	2048.73	740.19	2369.40	2963.86
HD	4077.53	964.68	5213.59	4913.74

According to the data of TABLE II, using C2R model, using Matlab software to solve, which take  $\alpha = 10^{-10}$ , get the evaluation results of carbon emissions of each city in Hebei Province by 2015.As TABLE III follows.

As the definition shows: The  $\theta^*$  of the cities as Qinhuangdao(DMU4),Baoding(DMU7),Hengshui(DMU9),Xingtai(DMU10) are one, and the slack variables as  $s^*=0$ ,  $s^{*+}=0$ , So they are all effective DEA. Shijiazhuang(DMU1), Chengde(DMU2),Zhangjiakou (DMU3), Tangshan(DMU5), Langfang(DMU6),Cangzhou(DMU8), Handan(DMU11),are valid DEA,the improvement suggestions are shown in TABLE IV as follows:

TABLE III. THE EVALUATION RESULTS OF CARBON EMISSIONS OF EACH CITY IN HEBEI PROVINCE BY 2015

DMU	$\theta^*$	$\sum_{j=1}^n \lambda_j$	Technical efficiency	Economies of scale	Effectiveness
DMU1(SJZ)	0.911	4.104	valid	decreasing	valid
DMU2(CD)	0.801	1.269	valid	decreasing	valid
DMU3(ZJK)	0.859	0.882	valid	ascending	valid
DMU4(QHD)	1.000	1.000	effective	constant	effective
DMU5(TS)	0.807	6.307	valid	decreasing	valid
DMU6(LF)	0.750	2.130	valid	decreasing	valid
DMU7(BD)	1.000	1.000	effective	constant	effective
DMU8(CZ)	0.819	3.279	valid	valid	valid
DMU9(HS)	1.000	1.000	effective	constant	effective
DMU10(XT)	1.000	1.000	effective	constant	effective
DMU11(HH)	0.824	2.955	valid	decreasing	valid

TABLE IV. ECONOMIC EVALUATION OF CARBON EMISSIONS OF EACH CITY IN HEBEI PROVINCE

DMU		Input	Output		
		Carbon emissions (Ten thousand tons)	Population (Ten thousand)	GDP (One hundred million yuan)	Energy Consumption (Ten thousand tons standard coal)
DMU1 (SJZ)	Current figure	4760.88	1075.19	7423.06	6121.09
	Improved figure	4339.54	1375.59	7423.06	6121.09
DMU2 (CD)	Current figure	1446.55	357.08	2395.93	1500.83
	Improved figure	1158.83	398.08	2395.93	1500.83
DMU3 (ZJK)	Current figure	1516.93	450.78	2139.82	1835.56
	Improved figure	1304.26	450.78	2139.82	1835.56
DMU5 (TS)	Current figure	9982.99	788.25	10635.82	12395.06
	Improved figure	8063.26	2321.25	10635.82	12395.06
DMU6 (LF)	Current figure	4839.44	464.88	3091.04	6132.19
	Improved figure	3631.52	919.18	3091.04	6132.19
DMU8 (CZ)	Current figure	6937.86	744.64	4705.29	9638.91
	Improved figure	5683.49	1428.54	4705.29	9638.91
DMU11 (HD)	Current figure	4077.53	964.68	5213.59	4913.74
	Improved figure	3360.70	1025.48	5213.59	4913.74

TABLE IV shows,Shijiazhuang's DEA is invalid, in order to achieve DEA effective, we should reduce inputs, that should reduce carbon emissions 4,213,400 tons, increase the volume of output, that population increased 3.004 million; Chengde's DEA is invalid, in order to achieve DEA effective, we should reduce inputs, that should reduce carbon emissions 2,877,200 tons, increase the volume of output, that population increased 0.41million; Zhangjiakou's DEA is invalid, in order to achieve DEA effective, we should reduce inputs, that should reduce carbon emissions 2,126,700 tons; Tangshan's DEA is invalid, in order to achieve DEA effective, we should reduce inputs, that should reduce carbon emissions 19,197,300 tons, increase the volume of output, that population increased 15.33 million; Langfang's DEA is invalid, in order to achieve DEA effective, we should reduce inputs, that should reduce carbon emissions 10,279,200 tons, increase the volume of output, that population increased 4.543 million; Cangzhou's DEA is invalid, in order to achieve DEA effective, we should reduce inputs, that should reduce carbon emissions 12,543,700 tons, increase the volume of output, that population increased 6.893 million; Handan's DEA is invalid, in order to achieve DEA effective, we should reduce inputs, that should reduce carbon emissions 7,168,300 tons, increase the volume of output, that population increased 0.608 million.

In order to achieve the national carbon emissions intensity decreased by 17% target in 2015 than in 2010, Hebei Province should reach the national average target at least, that in 2015

the province's carbon intensity decreased by 17% compared to 2010. According to estimates, in 2010, Hebei Province's carbon intensity is 1.0867t / ten thousand yuan, without the implementation of low-carbon development strategies, according to the current model of economic development and speed, according to the forecast, the province's carbon intensity 0.9150t / ten thousand yuan in 2015, although carbon intensity showed a decline compared to 2010, a decrease of 15.8%, did not meet the target that the province's 2015 carbon intensity of 17% decline compared to 2010. According to DEA evaluation results, after improving the cities whose DEA is weaker effective or ineffective, make the cities' DEA is effective, then according to the results of calculations, after the improvement, the province's carbon intensity may be 0.783t / ten thousand yuan in 2015, decreased by 27.9% compared to 2010, fully able to achieve carbon emission reduction target of 17%.

#### IV. CONCLUSION AND OUTLOOK

Now Hebei province is undergoing a rapid period of urbanization and industrialization. With the rapid economic development and the continuous improvement of living standards, the requirement for energy grows more and more rapidly. Coal is the main energy in China's energy structure, it causes massive release of greenhouse gases, such as carbon dioxide. How Hebei province both to achieve sustained economic growth, but also to effectively reach their emission reduction targets. For this, the aim of overall carbon reduction targets of "2015 national carbon emissions intensity by 17% compared to 2010". Clearing the carbon emission reduction responsibility in Hebei Province. First of all, predicting the input and output variables of DEA model. Then the paper uses DEA model to progress the efficiency analysis and economic evaluation for 11 prefecture-level city in Hebei carbon emissions in 2015. It obtains carbon emission allocating options of DEA efficiency and some suggestions are put forward. The results show that to achieve economic development in the reduction process is entirely possible. It provides a reference for the development of a low carbon economy over the level city in Hebei province.

#### V. SHORTCOMINGS

A. The distribution of carbon reduction responsibilities. After the development of a low carbon economy over the level city in Hebei province to provide a reference. The total amount of carbon emission reduction target has a fixed feature. So this paper can only get the initial calculation of the responsibility of the regional distribution of carbon emissions relative efficiency. The results can not be achieved by adjusting the allocation of areas to enhance the efficiency of the DEA.

B. Determining the distribution plan must consider both the principles of fairness and efficiency. Allocation scheme can only meet DEA effective and And does not reflect the fairness of allocation in this paper.

For these shortcomings it still need to conduct in-depth and meticulous research.

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