Research on CO$_2$ Emission Efficiency and Emission Reduction Potential in Beijing-Tianjin-Hebei Region

Ningning Liang*
School of Management, Tianjin University of Technology, Tianjin, China

*Corresponding author e-mail: 824492442@qq.com

Abstract. In the context of Beijing-Tianjin-Hebei coordinated development strategy, the paper selects 13 cities in Beijing-Tianjin-Hebei region as research objects, the CO$_2$ emission efficiency and emission reduction potential of each city are analyzed in order to provide reference for achieving the target of carbon emission peak through coordinated reduction among cities. Firstly, the emission efficiency of CO$_2$ of 13 cities in Beijing, Tianjin and Hebei in 2005-2014 was estimated using the non expected output SBM model. Then, the emission reduction potential of cities is quantitatively analyzed based on equity and efficiency of the emission reduction potential index. The results show that the overall carbon emission efficiency of Beijing-Tianjin-Hebei city is decreasing during the research period. The urban emission reduction potential index has the same trend, and Beijing has the lowest emission reduction potential and Tangshan has the highest emission reduction potential.

Keywords: Beijing-Tianjin-Hebei region; CO$_2$ emission efficiency; CO$_2$ emission reduction potential.

1. Introduction
The development of China's economy is in an important stage of rapid urbanization in the late stage of industrialization. The characteristics of this stage determine that the carbon dioxide emissions will increase with economic development in China at a high speed[1]. During the 2014 APEC meeting, Xi announced China plans to peak its carbon dioxide emissions around 2030 and will strive to reach their peak early. However, China faces enormous challenges in achieving an early peak in carbon emissions, including economic, energy and technological synergies and trade-offs. 70% of China's CO$_2$ emissions come from cities[2]. Therefore, the achievement of the country's low-carbon development policy and the peak carbon emission targets largely depends on the emission efficiency and emission reduction potential of cities, it has important theoretical and practical significance to consider these two aspects as a whole. With the implementation of the “beijing-tianjin-hebei coordinated development planning outline”, Handan as the main body of the beijing-tianjin-hebei city economic, social and ecological environment of scientific and coordinated development has risen to the national strategy. In this context, this paper will focus on the analysis of CO$_2$ emission efficiency and emission reduction potential of Beijing, Tianjin and Hebei Cities, in order to make a more rational and effective emission reduction policy in Beijing-Tianjin-Hebei coordinated development process, and to achieve the emission peak through inter-city coordinated emission reduction targets to provide reference.
2. Literature review

Current research on carbon emissions has focused on the following two aspects. The first is to study the emission reduction policy, emission reduction cost and emission reduction target. It also explores how to make the emission policies and targets more rational to ensure sustainable development of the economy and society. As Shinkuma shows, emissions trading is better than tax policy when the information is asymmetric over a long period of time[3] Indigenous peoples. The use of regulatory optimal planning models such as Gao Yang and others shows that the implementation of carbon emissions trading can optimize socio-economic costs[4]. Secondly, carbon emission intensity, carbon emission quota, carbon emission efficiency and emission reduction potential are studied from industry and region level. In the research on carbon emission efficiency and emission reduction potential, sun aijun et al. measured the carbon emission efficiency of China's export trade by using the malmquist-luenberger model containing non-expected output[5]. Huajian et al. used three-stage DEA to evaluate China's regional carbon dioxide emissions performance, and found that China's inter-regional carbon emissions performance development is significantly unbalanced [6].

3. Research methods and data sources

3.1. Carbon dioxide emission efficiency measurement method

According to Tone’s approach to solving the problem of slack in input and output and the problem of efficiency measurement in the presence of undesired outputs (Slack-based Measure,SBM)[7] , select each city in the Beijing-Tianjin-Hebei region as a decision-making unit. Each decision-making unit has three inputs and outputs, inputs, expected outputs, and undesired outputs (CO₂ emissions). Elements can be represented as: $x \in \mathbb{R}^m$, $y^g \in \mathbb{R}^l$, and $y^b \in \mathbb{R}^2$, respectively, then the set of production possibilities can be defined as:

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

In the formula: $x > 0$, $y^g > 0$, $y^b > 0$. $\lambda$ is the weight vector. If the production technique is a variable-scale reward, then the constraint of $\lambda = 1$ needs to be increased, where $l$ is a vector with all elements being 1, otherwise it is a constant scale reward. Based on the definition of the set of production possibilities, the SBM model considering the undesired output is:

$$\rho^* = \min \left\{ \frac{1}{m} \sum_{i=1}^{m} \frac{s_i^g}{x_{i0}} \left| \begin{array}{c}
1 + \frac{1}{s_1 + s_2} \left( \sum_{r=1}^{s_1} \frac{s_r^g}{y_{t0}} + \sum_{r=1}^{s_2} \frac{s_r^b}{y_{r0}} \right) \\
\begin{array}{l}
x_0 = \lambda X + s^- \\
y^g_0 = \lambda Y^g - s^g \\
y^b_0 = \lambda Y^b + s^b \\
s^- \geq 0, s^g \geq 0, s^b \geq 0, \lambda \geq 0,
\end{array}
\end{array} \right. \right\}$$ (2)

$s$ is the amount of slack in input and output; $\lambda$ is the weight vector; $\rho^*$ is the objective function, which is strictly decremented with respect to $s^g$, $s^b$, and $0 \leq \rho^* \leq 1$. For a particular decision unit, it is efficient if and only if $\rho^* = 1$, ie $s^g = 0$, $s^b = 0$, $s^b = 0$.

3.2. Carbon dioxide emission reduction potential index

Drawing on the research of Wei[8], et al, this paper uses the Carbon Emission Reduction Potential Index (ACI), which considers both the fairness principle and the efficiency principle, to reflect the emission reduction potential. The larger the value, the greater the emission reduction potential. The expression is:

$$ACI_{it} = \omega \times Equity_{it} + (1 - \omega) \times Efficiency_{it}$$ (3)

Where $i$ is the city; $t$ is the time; $\omega$ is the weight; $Efficiency_{it}$ is the emission fairness index of the city $i$ in the period $t$, $Efficiency_{it}$ is the emission efficiency index.
3.3. Data Sources

In this paper, 13 cities in Beijing, Tianjin, and Hebei are selected as the research objects, and the research time span is selected from 2005 to 2014. Based on the above research methods, CO₂ emission efficiency calculations are performed. Capital stock, labor, and energy consumption in cities of Beijing, Tianjin, and Hebei as input factors, Urban GDP and CO₂ emissions as expected output and non expected output indicators; When calculating the emission reduction potential index, four indexes are selected: per capita carbon dioxide emissions, per capita gross domestic product, CO₂ emission intensity and CO₂ emission shadow price. The basic data of the selected indicators are all from the yearbook of Chinese city statistics, yearbook of Chinese energy statistics, yearbook of Chinese environment, statistical yearbook of Beijing, Tianjin, and Hebei, statistical yearbook of Hebei cities, statistical bulletin and other data, and are properly processed.

4. Analysis of calculation results

4.1. Carbon dioxide emission efficiency analysis

The SBM Model with unexpected output considered above, using DEA Solver 5.0 software, the CO₂ emission efficiencies of 13 cities in Beijing, Tianjin, and Hebei in 2005-2014 are measured and the results are shown in Table 1.

| Year | Beijing | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | Mean value |
|------|---------|------|------|------|------|------|------|------|------|------|------|------------|
|      | 1       | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1          |
| Tianjin | 1   | 0.738 | 0.672 | 0.660 | 0.624 | 0.610 | 1    | 1    | 1    | 0.830 |
| Shijiazhuang | 0.456 | 0.455 | 0.434 | 0.416 | 0.407 | 0.393 | 0.403 | 0.393 | 0.367 | 0.379 | 0.410 |
| Chengde | 1 | 1 | 0.824 | 0.781 | 0.774 | 0.747 | 0.755 | 0.744 | 0.699 | 0.640 | 0.796 |
| Zhangjiakou | 0.755 | 0.738 | 0.714 | 0.657 | 0.621 | 0.583 | 0.593 | 0.585 | 0.566 | 0.581 | 0.639 |
| Qinhuangdao | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Tangshan | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Langfang | 0.637 | 0.625 | 0.585 | 0.565 | 0.562 | 0.632 | 0.627 | 0.619 | 0.584 | 0.606 | 0.604 |
| Baoding | 0.496 | 0.522 | 0.520 | 0.492 | 0.480 | 0.458 | 0.463 | 0.452 | 0.430 | 0.459 | 0.477 |
| Cangzhou | 0.483 | 0.816 | 0.557 | 0.520 | 0.510 | 0.491 | 0.502 | 0.479 | 0.443 | 0.457 | 0.526 |
| Hengshui | 0.615 | 0.705 | 1 | 1 | 1 | 1 | 1 | 1 | 0.782 | 1 | 0.910 |
| Xingtai | 0.471 | 0.484 | 0.463 | 0.457 | 0.455 | 0.451 | 0.486 | 0.482 | 0.453 | 0.462 | 0.466 |
| Handan | 0.474 | 0.485 | 0.447 | 0.414 | 0.397 | 0.382 | 0.393 | 0.381 | 0.350 | 0.348 | 0.407 |
| Mean value | 0.722 | 0.736 | 0.709 | 0.653 | 0.639 | 0.632 | 0.709 | 0.699 | 0.625 | 0.644 | 0.752 |

Table 1 shows, Only Beijing and Qinhuangdao have an average carbon emission efficiency of 1 in 13 cities in Beijing, Tianjin, and Hebei. It suggests that the carbon efficiency of both cities is on the production front, to control carbon dioxide emission level reasonably to drive economic development, the average emission efficiency of other cities failed to reach the production frontier. Changes in mean carbon emission efficiency in Beijing, Tianjin, and Hebei from 2005 to 2014, a downward trend was observed, with a decline from 0.722 in 2005 to 0.644 in 2014. This is mainly due to the decline in carbon efficiency in most cities in Hebei Province, where the emission efficiency of most cities has shown a downward trend, this is because the level of economic development in these cities is lower than that of Beijing and Tianjin, where the level of urbanization is lower. The development of new industrialization and urbanization in these cities still rely on high investment, high consumption and high emission mode of economic development, Therefore, the overall carbon emission efficiency of Beijing-Tianjin-Hebei city has decreased in this period.
4.2. Analysis of CO₂ emission reduction potential

Based on the CO₂ abatement potential index model, considering the principle of fairness and principle of efficiency with equal weight; The weight of the formula (3) will be 0.5. The emission reduction potential of cities in Beijing, Tianjin and Hebei in 2005-2014 is calculated and the detailed results are shown in Table 2.

| Year | Beijing | Tianjin | Shijiazhuang | Chengde | Zhangjiakou | Qinhuangdao | Tangshan | Langfang | Baoding | Cangzhou | Langfang | Xingtai | Handan |
|------|---------|---------|-------------|---------|------------|-------------|----------|----------|---------|----------|----------|---------|--------|
| 2005 | 0.287   | 0.595   | 0.519       | 0.366   | 0.417      | 0.440       | 0.870    | 0.479    | 0.354   | 0.483    | 0.440    | 0.482   | 0.507   |
| 2006 | 0.280   | 0.528   | 0.518       | 0.374   | 0.433      | 0.453       | 0.879    | 0.500    | 0.357   | 0.489    | 0.435    | 0.486   | 0.528   |
| 2007 | 0.273   | 0.515   | 0.521       | 0.442   | 0.444      | 0.463       | 0.885    | 0.500    | 0.360   | 0.489    | 0.418    | 0.483   | 0.535   |
| 2008 | 0.266   | 0.506   | 0.524       | 0.467   | 0.463      | 0.459       | 0.907    | 0.507    | 0.359   | 0.481    | 0.415    | 0.470   | 0.539   |
| 2009 | 0.257   | 0.509   | 0.529       | 0.458   | 0.467      | 0.456       | 0.929    | 0.508    | 0.363   | 0.489    | 0.405    | 0.466   | 0.536   |
| 2010 | 0.251   | 0.550   | 0.519       | 0.466   | 0.482      | 0.463       | 0.943    | 0.505    | 0.367   | 0.505    | 0.412    | 0.466   | 0.537   |
| 2011 | 0.238   | 0.630   | 0.531       | 0.492   | 0.494      | 0.471       | 0.952    | 0.518    | 0.384   | 0.525    | 0.427    | 0.472   | 0.549   |
| 2012 | 0.233   | 0.620   | 0.532       | 0.494   | 0.506      | 0.470       | 0.947    | 0.525    | 0.390   | 0.520    | 0.436    | 0.472   | 0.553   |
| 2013 | 0.235   | 0.627   | 0.546       | 0.492   | 0.519      | 0.469       | 0.938    | 0.534    | 0.401   | 0.530    | 0.439    | 0.477   | 0.557   |
| 2014 | 0.236   | 0.623   | 0.538       | 0.494   | 0.519      | 0.489       | 0.927    | 0.535    | 0.387   | 0.512    | 0.427    | 0.472   | 0.555   |

Calculation based on the emission reduction potential index mentioned above, equity and efficiency of CO₂ emission reduction in Beijing, Tianjin and Hebei Cities; average of the results of the fairness and efficiency indices by city over a 10-year period. The 13 cities in Beijing, Tianjin and Hebei are divided into four categories: “Fairer and More Efficient”, “Less Efficient”, “Less Equitable and More Efficient” and “Less Equitable and More Inefficient” The breakdown results are shown in Figure 1.

**Figure 1.** Category result of each city based on equity index and efficiency index

The results of the classification shown in Figure 1, Hebei’s xingtai, hengshui, zhangjiakou, handan, chengde, cangzhou, langfang, qinhuangdao and other eight cities, tangshan and shijiazhuang belong to “fair and efficient” city with emission reduction, Both cities are above the average in terms of fairness.
and efficiency in Beijing, Tianjin and Hebei, this is mainly due to the high per capita carbon emissions and carbon intensity in the two cities. Baoding belongs to “unfair low efficiency” city, Beijing, Tianjin belong to “relatively fair low efficiency” city.

5. Conclusion
Combined emission efficiency and emission reduction potential results, Cities in 13 cities in Beijing, Tianjin and Hebei with low emission efficiency index but high emission reduction potential, such as Shijiazhuang, Tangshan, Langfang, Cangzhou and Handan should undertake relatively large emission reduction responsibilities. Cities with lower emission efficiency but low emission reduction potential, such as chengde, zhangjiakou, baoding, hengshui, xingtai and other cities in the control of carbon emissions must also achieve economic development.

References
[1] Liu Y S, Yan B, Zhou Y. Urbanization, economic growth, and carbon dioxide emissions in China: A panel co-integration and causality analysis[J]. Journal of Geographical Science, 2016, 26 (2) :131-152.
[2] Wei C. China’s urban carbon dioxide marginal abatement cost and its influencing factors[J]. World Economics, 2014, 37 (7) :115-141.
[3] Shinkuma T, Sugeta H. Tax versus emissions trading scheme in the long run[J]. Journal of Environmental Economics and Management, 2015, 75:12-24.
[4] Gao Y, Li J. Optimal choice of carbon emissions reduction policy instruments considering cost effectiveness[J]. Systems Engineering, 2014, 32 (6) :119-125.
[5] Sun A J, Fang J T, Wang Q W. Dynamic distribution and evolution of carbon dioxide emission efficiency in China’s export trade[J]. Resources Science, 2015, 37 (6) :1230-1238.
[6] Hua J, Ren J, Xu M. Evaluation of Chinese regional carbon dioxide emissions performance based on a three-stage DEA model[J]. Resources Science, 2013, 35 (7) :1447-1454.
[7] Tone K. A slacks-based measure of efficiency in data envelopment analysis[J]. European Journal of Operation Research, 2001, 130 (3) :67-71.
[8] Wei C, Ni J L, Du L M. Regional allocation of carbon dioxide abatement in China[J]. China Economic Review, 2012, 23 (3) :552-565.