Potential and contribution factors of carbon emission reduction in the power sector of BTH (Beijing-Tianjin-Hebei) region

Yanghe Gao¹, Wenxuan Li¹, and Ren Huang²,*

¹North China Branch of State Grid Corporation, China
²North China Electric Power University, School of Economics and Management, Beijing, China
* Corresponding author: hr19961129@163.com

Abstract. Beijing-Tianjin-Hebei region is not only the national key strategic development area, but also the main battlefield of low-carbon transformation. Beijing-Tianjin-Hebei region accounts for about 1/5 of the national carbon emissions, of which the power sector accounts for a large proportion of carbon emissions. Therefore, the research on the carbon reduction potential and contribution factors of Beijing-Tianjin-Hebei power sector is of great strategic significance to the achievement of BTH Coordinated Development and carbon neutralization strategy. Based on the comprehensive consideration of power generation, transmission, power consumption, power supply and other links, this paper constructs a bottom-up accounting model of CO₂ emissions in power industry, and studies the main driving factors affecting carbon emissions by using LMDI method.

1. Introduction
Since 2006, China has been the world largest carbon emitter. Currently it accounts for around 28% of global carbon emissions. In Sept. 2020 China announced to have its carbon emissions peak before 2030 and achieve carbon neutrality before 2060. Carbon neutrality is an economy-wide challenge, requiring substantial emissions reductions across all sectors of the economy. Power provides greater opportunities for emissions reductions relative to other sectors, due to the many low-carbon power generation options and the increasing competitiveness of wind and solar power in particular. Although detailed strategies or pathways have yet to be rolled to carbon neutrality, it is imperative to look into strategies or pathways on provincial and regional scale.

Beijing—Tianjin—Hebei (the BTH) region is located in northern China, covering two megacities—Beijing (China’s capital) and Tianjin and one province—Hebei Province. By the end of 2019, this region has a population of 113.08 million accounting for 8.08% and contributes 8.56% of GDP in China. Beijing—Tianjin—Hebei (the BTH) region is located in northern China, covering two megacities—Beijing (China’s capital) and Tianjin and one province—Hebei Province. In 2019, three of China’s top 10 highly polluted cities were located in this region[1]. And in 2017, this region accounted for 9.65% of the total emissions in the country, the main reason for this is its power structure dominated by coal-fired power. According to the IEA, the largest share of emissions came from power and heat (51%), followed by industry (28%) and transportation (10%). The objective of this paper is to examine the potential and contribution factors of carbon emission reduction in the power sector of the BTH region. This paper is organized as follows: Section 2 establishes a bottom-up carbon emission accounting model for the BTH power sector and designs three scenarios in light of various policy documents and plans released by the governments in Beijing, Tianjin and Hebei; Section 3 analyze the potential and contribution factors of
carbon emissions reduction in the BTH power sector din the year 2025 and 2030 respectively based on three different policy scenarios; Section 4 provides conclusions and policy implications.

2. Method

In order to more directly and systematically reflect the carbon emission path in the power sector, this section constructs a bottom-up accounting model of carbon emission in the BTH power sector referring to Gu [2]. Main variables cover end-use power consumption, the proportion of low-carbon energy generation, the internal structure of thermal power, import power rate, thermal power generation efficiency and transmission line loss rate. The structure decomposition is shown in Fig. 1.

![Decomposition of carbon emission structure in BTH power sector](image)

As regards the power structure in the BTH region, the low-carbon power sources selected in this model only includes wind, solar PV, and hydropower whilst thermal power includes coal-, oil-, and gas-power. Because low-carbon power generation does not produce carbon emissions, only the carbon emissions from thermal power generation need to be calculated, which is mainly determined by thermal power structured the power generation efficiency of various thermal power plants. Therefore, the carbon emissions accounting model in BTH power sector is constructed as follows:

\[
CE = \sum_{i \in \psi} \frac{P}{1-\mu} \times (1-b) \times (1-a) \times TP_i \times EF_i \times e_i
\]  

(1)

Where, \(CE\) is the total carbon emissions in the power sector; \(CE_i\) is the carbon emissions of thermal power type \(i\); \(\psi\) is a collection of different thermal power structures, including coal, oil, and gas power generation; \(P\) is end-use power consumption; \(\mu\) is the rate of power transmission line loss; \(a\) and \(b\) are the proportion of low-carbon energy generation and import power respectively; \(TP_i\) is the proportion of type \(i\) thermal power generation in the total thermal power generation; \(EF_i\) is the fuel consumption per unit generating capacity of thermal power type \(i\); \(e_i\) is the carbon emission factor of the fuel consumption of thermal power plant type \(i\).

For the convenience of decomposition, the variables in equation (1) is simplified as follows: \(1/1-\mu = U\), \(1-a = A\), \(1-b = B\). Thus, formula (1) is changed as follows:

\[
CE = \sum_{i \in \psi} CE_i = \sum_{i \in \psi} P \times U \times B \times A \times TP_i \times EF_i \times e_i
\]  

(2)

Index decomposition method (IDA) is a common method to explore the influencing factors of carbon emissions changes. Logarithmic Mean Divisia Index (LMDI) is a more reasonable method in IDA, which can not only decompose the remainder completely but also deal with non-positive values properly [3-4]. Therefore, considering the advantages of the LMDI model, we use LMDI to decompose the
contribution factors of carbon emissions reduction based on previous carbon emissions accounting model. Introducing logarithmic mean function $L$ as equation (3).

$$L(x, y) = \begin{cases} \frac{x-y}{\ln x - \ln y}, & x \neq y \\ \frac{x}{y}, & x = y \\ 0, & x = y = 0 \end{cases}$$ (3)

Using the LMDI decomposition method, equation (2) can be decomposed into the following forms:

$$\Delta CE = CE_T - CE_0 = \Delta P + \Delta U + \Delta B + \Delta A + \Delta TP + \Delta EF$$

$$\Delta P = \sum_{i \in \Psi} L(CE_{i,T}, CE_{i,0}) \ln \frac{P_T}{P_0}$$

$$\Delta U = \sum_{i \in \Psi} L(CE_{i,T}, CE_{i,0}) \ln \frac{U_T}{U_0}$$

$$\Delta A = \sum_{i \in \Psi} L(CE_{i,T}, CE_{i,0}) \ln \frac{A_T}{A_0}$$

$$\Delta B = \sum_{i \in \Psi} L(CE_{i,T}, CE_{i,0}) \ln \frac{B_T}{B_0}$$

$$\Delta TP = \sum_{i \in \Psi} L(CE_{i,T}, CE_{i,0}) \ln \frac{TP_{i,T}}{TP_{i,0}}$$

$$\Delta EF = \sum_{i \in \Psi} L(CE_{i,T}, CE_{i,0}) \ln \frac{EF_{i,T}}{EF_{i,0}}$$

Where, $\Delta CE = CE_T - CE_0$ represents the change of carbon emissions of power sector from initial year 0 to year T, and the other variables represent the contribution factors to the change of carbon emissions in the power sector, of which $\Delta P$ is the effect of end-use power consumption, that is, the impact of end-use power consumption on carbon emissions, $\Delta U$ is the effect of transmission line loss, that is, the impact of line loss rate on carbon emissions, $\Delta B$ is the effect of power import, that is, the impact of power import rate on carbon emissions, $\Delta A$ is the effect of low-carbon power generation, that is, the impact of renewable energy generation ratio on carbon emissions. $\Delta TP$ is the internal structure effect of thermal power, that is, the impact of the proportion of various thermal power generation on carbon emissions. $\Delta EF$ is the efficiency effect of thermal power generation, that is, the impact of fuel consumption per unit of thermal power generation on carbon emissions.

3. Potential and contribution of carbon emissions reduction in the BTH region

This paper assumes three policy scenarios for Beijing, Tianjin and Hebei, including baseline policy scenario, current policy scenario, and low-carbon policy scenario. Each policy scenario is based on different policy assumptions and represents different development paths. Parameters in Beijing, Tianjin and Hebei are based on the energy and power policies, development plans, research reports of professional institutions.

Putting the scenario parameters of BTH into equation (1), the carbon emissions in BTH power sector from 2006 to 2030 are obtained. As shown in Fig. 2, Fig. 3 and Fig. 4. Under the current scenario and low-carbon scenario, the carbon emissions of the three power sectors will continue to decline, and the carbon emission reduction potential is Hebei Province, Tianjin city and Beijing city respectively. Carbon emissions in Beijing's power sector reached its peak in 2013, with a total of 18.88 million tons carbon emission. Carbon emissions in Tianjin's power sector reached its peak in 2011, with a total of 58.99
million tons carbon emission. Carbon emissions in Hebei's power sector reached its peak in 2011, with a total of 209.76 million tons carbon emissions.

Fig. 2  Carbon emissions in Beijing power sector in different scenarios from 2006 to 2030 (Unit: Million tons)

Fig. 3  Carbon emissions in Tianjin power sector in different scenarios from 2006 to 2030 (Unit: Million tons)

Fig. 4  Carbon emissions in Hebei power sector in different scenarios from 2006 to 2030 (Unit: Million tons)
The LMDI model is used to decompose the contribution factors of carbon emissions in Beijing, Tianjin and Hebei power sector\cite{5-7}, and the results are shown in Table 1, Table 2 and Table 3.

It can be seen that end-use power consumption is the main contribution factor of carbon emission in BTH power sector.

Table 1  Decomposition results of carbon emission reduction in Beijing power sector from 2017 to 2030

|               | Baseline scenario | Current scenario | Low-carbon scenario |
|---------------|-------------------|------------------|---------------------|
|               | CO2 rate          | CO2 rate         | CO2 rate            |
| ∆P            | 7.1 100%          | 4.24 80.19%      | 3.73 52.88%         |
| ∆U            | 0 0%              | -0.03 0.61%      | -0.06 0.89%         |
| ∆A            | 0 0%              | -2.94 55.62%     | -3.2 45.30%         |
| ∆TP           | 0 0%              | -0.41 7.77%      | -0.4 5.64%          |
| ∆B            | 0 0%              | -2.9 54.84%      | -3.19 45.12%        |
| ∆EF           | 0 0%              | -3.24 61.35%     | -3.95 55.92%        |
| ∆CE           | 7.1 100%          | -5.29 100.0%     | -7.06 100.0%        |

Table 2  Decomposition results of carbon emission reduction in Tianjin power sector from 2017 to 2030

|               | Baseline scenario | Current scenario | Low-carbon scenario |
|---------------|-------------------|------------------|---------------------|
|               | CO2 rate          | CO2 rate         | CO2 rate            |
| ∆P            | 31.2 100.0%       | 20.3 142.9%      | 16.9 67.45%         |
| ∆U            | 0 0.00%           | -0.2 1.15%       | -0.2 0.83%          |
| ∆A            | 0 0.00%           | -5.9 41.37%      | -7.0 27.80%         |
| ∆TP           | 0 0.00%           | -6.6 46.44%      | -6.8 26.95%         |
| ∆B            | 0 0.00%           | -8.0 56.46%      | -12.9 51.53%        |
| ∆EF           | 0 0.00%           | -13.8 97.54%     | -15.1 60.34%        |
| ∆CE           | 31.2 100.0%       | -14.2 100.0%     | -25.1 100.0%        |

Table 3  Decomposition results of carbon emission reduction in Hebei power sector from 2017 to 2030

|               | Baseline scenario | Current scenario | Low-carbon scenario |
|---------------|-------------------|------------------|---------------------|
|               | CO2 rate          | CO2 rate         | CO2 rate            |
| ∆P            | 123.4 100.0%      | 79.0 165.1%      | 63.0 69.25%         |
| ∆U            | 0 0.00%           | -0.6 1.21%       | -0.7 0.80%          |
| ∆A            | 0 0.00%           | -49.3 103.0%     | -45.4 49.89%        |
| ∆TP           | 0 0.00%           | -24.7 51.63%     | -42.9 47.13%        |
| ∆B            | 0 0.00%           | -15.2 31.74%     | -21.3 23.44%        |
| ∆EF           | 0 0.00%           | -37.1 77.48%     | -43.7 48.00%        |
| ∆CE           | 123.4 100.0%      | -47.8 100.0%     | -91.0 100.0%        |

4. Conclusions and policy implications

This paper firstly constructs a bottom-up carbon emissions accounting model for the power sector, and then it uses scenario analysis and LMDI index decomposition method to examine the potential and contribution factors of carbon emissions reduction in Beijing, Tianjin, and Hebei, respectively. The main conclusions are as follows:
(1) End-use power consumption is the primary contribution factor of carbon emission in BTH power sector.

(2) Under the current scenario and low-carbon policy scenarios, the carbon emissions of the power sectors in Beijing, Tianjin and Hebei would continue to decline, and the carbon emission reduction potential, in descending order, is Hebei (171.24—214.44 million tons), Tianjin (45.44—55.36 million tons), and Beijing (12.39—14.17 million tons) respectively.

(3) The proportion of low-carbon energy power generation, thermal power generation efficiency, and power import are the main contributors of carbon emission reduction in the BTH power sector.

Based on the above research results, this paper puts forward the following policy recommendations:

(1) Improve energy saving and energy efficiency. In the context of the current energy structure dominated by fossil energy in the BTH region, energy saving and efficiency improvement is the leading force of emission reduction.

(2) Enhance the support for emission reduction in Tianjin and Hebei. The potential of carbon emission reduction in Hebei and Tianjin power sector is huge, which together is 17 times that of Beijing. It is thus imperative to enhance policy support for emission reduction in Tianjin and Hebei.

(3) Improve the efficiency of thermal power generation. It is shown that in the short term, coal-fired power will continue to be in a dominated position in the power generation in Tianjin and Hebei. Therefore, reducing coal consumption for power generation will be the main approach of carbon emission reduction in their power sector.

(4) The proportion of gas-fired power generation should be appropriately increased according to local conditions, and the structure of thermal power should be optimized.

(5) Pay attention to the selection and optimization of incremental power plants, and increase the proportion of renewable energy power generation.

Acknowledgement
The study was supported by the National Natural Science Foundation of China (Project No. 71934006), the Beijing Social Science Foundation (Grant No. 19JDYJA003) and the North China Branch of State Grid Corporation of China (Grant No. KH4189).

References
[1] Yue Y., Zhi X., Journal of Cleaner Production 275:12375 (2020)
[2] Gu B., Tan X., Journal of ecology, 35(19):6405-6413 (2015)
[3] Ang B., Energy Policy, 32(9):1131-1139 (2004)
[4] Ang B., Energy Policy, 86:233-238 (2015)
[5] Zhao X., Ma Q., Yang R., Energy Policy, 57:89-98 (2013)
[6] Xie P., Gao S., Sun F., Journal of Cleaner Production, 221: 598-606 (2019)
[7] Meng M., Jing K., Journal of Cleaner Production, 142: 3101-3108 (2016)