A Potential Model of Electric Energy Substitution for Environmental Protection Based on Emission Reduction Targets

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Abstract. In this paper, we propose a potential model of electric energy substitution for environmental protection based on emission reduction targets. By analyzing the environmental capacity under the constraint of PM2.5 compliance by region and main pollutant emission in waste gas by region, we obtained the emission reduction targets by region (either SO2 or NOx). Then, we can calculate the potential of electric energy substitution by region based on the effect of electricity emission reduction. Calculation shows that the potential of electric energy substitution for environmental protection in China is $2134.95 \times 10^9$ kwh.

Introduction

At present, the proportion of coal is high and the proportion of electrification is low in China, and a large amount of coal burning and fuel consumption is one of the main factors causing severe haze. Electric energy substitution means that electricity can replace the energy consumption mode of coal and fuel in the terminal energy consumption [1-3]. Thus, to implementation of electric energy substitution is an important measure to reduce air pollution.

According to the target of *The Environmental Macro Strategy Research and The Air Pollution Prevention Action Plan Target*, the Chinese government is committed to: the urban air quality should be basically standard in 2030, in other words, the concentration of particulate matter (PM) 2.5 should be less than 35 micrograms per cubic metre [4].

In this paper, we propose a potential model of electric energy substitution for environmental protection based on emission reduction targets [5]. By analyzing the environmental capacity under the constraint of PM2.5 compliance by region and main pollutant emission in waste gas by region, we obtained the emission reduction targets by region (either SO2 or NOx). Then, we can calculate the potential of electric energy substitution by region based on the effect of electricity emission reduction [6-8].

Potential Model of Electric Energy Substitution for Environmental Protection

Environmental Capacity under the Constraint of PM2.5 Compliance by Region

PM can be divided into primary PM and secondary PM. The primary PM is the PM that are released into the atmosphere by natural and anthropogenic sources of pollution, such as soil particles, sea salt particles, burning soot and so on. The secondary PM is composed of some polluting gas components in the atmosphere (e.g. sulfur dioxide (SO2), nitrogen oxide (NOx), and nitrogen and hydrogen compounds (NH3)) which is transformed into PM by photochemical oxidation, catalytic oxidation, or
other chemical reactions. Thus, there are four targets for urban air quality: annual emissions of SO$_2$, NOx, primary PM2.5 and NH$_3$ [9].

According to the department of atmospheric environment (Environmental Planning Institute, Ministry of Environmental Protection) estimates, environmental capacity under the constraint of pm2.5 compliance by region is shown in Table 1. That means if the pollutant emission in waste gas in a region is less than the environmental capacity for this region shown in Table 1, the air quality of the region can meet the standard.

### Table 1. Environmental capacity under the constraint of pm2.5 compliance (10$^4$ tons).

| Region         | SO$_2$ | NOx  | primary PM2.5 | NH$_3$ | Region         | SO$_2$ | NOx  | primary PM2.5 | NH$_3$ |
|----------------|-------|------|----------------|-------|----------------|-------|------|----------------|-------|
| Beijing        | 4.11  | 6.79 | 2.79           | 1.35  | Hubei          | 31.37 | 24.21| 21.67          | 29.09 |
| Tianjing       | 8.68  | 10.7 | 3.57           | 1.57  | Hunan          | 34.09 | 25.59| 18.03          | 29.07 |
| Hebei          | 48.58 | 51.19| 23.19          | 19.5  | Guangdong      | 68.95 | 105.72| 37.21          | 35.16 |
| Shanxi         | 85.37 | 66.08| 34.78          | 10.9  | Guangxi        | 50.5  | 38.4 | 41.15          | 32.16 |
| Inner Mongolia | 130.9 | 118.7| 42.67          | 39.5  | Hainan         | 3.11  | 8.03 | 3.18           | 6.84  |
| Liaoning       | 72.81 | 59.05| 29.12          | 20.4  | Chongqing      | 35.07 | 20.78| 14.32          | 15.55 |
| Jilin          | 32.53 | 42.98| 21.81          | 17.7  | Sichuan        | 37.9  | 23.88| 27.72          | 39.09 |
| Heilongjiang   | 39.19 | 55.01| 24.34          | 24.0  | Guizhou        | 63.81 | 23.2 | 19.04          | 16.92 |
| Shanghai       | 14.4  | 22.78| 5.4            | 1.7   | Yunnan         | 65.47 | 46.52| 31.76          | 47.26 |
| Jiangsu        | 52.38 | 63.37| 24.57          | 28.4  | Tibet          | 0.42  | 3.83 | 0.57           | 9.59  |
| Zhejiang       | 39.74 | 45.36| 14.15          | 11.5  | Shangxi        | 60.43 | 47.06| 21.5           | 19.15 |
| Anhui          | 20.78 | 30.71| 16.8           | 17.5  | Gansu          | 52.06 | 35.24| 18.51          | 17.64 |
| Fujian         | 39.05 | 43.71| 18.73          | 18.9  | Qinghai        | 14.37 | 9.89 | 5.98           | 6.85  |
| Jiangxi        | 41.86 | 39   | 16.1           | 16.4  | Ningxia        | 34.61 | 35.85| 6.85           | 5.91  |
| Shandong       | 70.92 | 57.17| 33.85          | 27.6  | Xinjiang       | 62.33 | 53.33| 17.75          | 24.73 |
| Henan          | 47.39 | 44.27| 21.92          | 35.3  | Total          | 1363.2| 1258.4| 619.04        | 627.7 |

### Main Pollutant Emission in Waste Gas by Region

Table 2 shows the main pollutant emission in waste gas by region based on China Statistical Yearbook 2017. Clearly, regions where emissions exceed environmental capacity (either SO$_2$ or NOx) need to implement electric energy substitution to reduce emissions.

### Table 2. Main pollutant emission in waste gas by region (10$^4$ tons).

| Region         | SO$_2$ | NOx  | Region         | SO$_2$ | NOx  | Region         | SO$_2$ | NOx  |
|----------------|-------|------|----------------|-------|------|----------------|-------|------|
| Beijing        | 3.32  | 9.61 | Shandong       | 113.4  | Shandong       | 113.4  | 5.42 | Shandong       | 113.4  |
| Tianjin        | 7.06  | 14.47| Qinghai        | 11.37 | 9.42 | Sichuan        | 48.83 | 45.10| Sichuan        | 48.83  |
| Hebei          | 78.9  | 112.6| Hunan          | 41.36 | 80.83| Guizhou        | 64.71 | 37.79| Guizhou        | 64.71  |
| Shanxi         | 68.6  | 67.28| Hubei          | 28.56 | 39.14| Yunnan         | 52.62 | 44.69| Yunnan         | 52.62  |
| Inner Mongolia | 62.5  | 64.53| Hunan          | 34.68 | 42.06| Tibet          | 0.54  | 5.52 | Tibet          | 0.54   |
| Shanxi         | 31.8  | 38.03| Guangdong      | 35.37 | 84.27| Shanghai       | 7.42  | 16.63| Shanghai       | 7.42   |
Emission Reduction Effect Estimation

In this section, we analyze and compare the emission reduction effect by calculating the conversion value of sulfur dioxide and the conversion value of nitrogen oxides for several typical terminal energy sources (coal, petrol, diesel, natural gas, kerosene).

a) Calculating the equivalent power value of terminal energy. \( E \) is the equivalent energy value of 1 units of terminal energy, that is, \( E \) kw·h electric energy is equal to the energy value of 1 units of terminal energy.

b) Calculating the conversion value of sulfur dioxide for terminal energy. \( S \) and \( C_{SO_2} \) respectively represents the sulfur dioxide emission factor and sulfur dioxide conversion value for 1 units of terminal energy. Calculate the sulfur dioxide conversion value of terminal energy by \( C_{SO_2} = S/E \).

c) Calculating the conversion value of nitrogen oxides for terminal energy. \( N \) and \( C_{NO_x} \) respectively represents the nitrogen oxides emission factor and nitrogen oxides conversion value for 1 units of terminal energy. Calculate the nitrogen oxides conversion value of terminal energy by \( C_{NO_x} = N/E \).

### Table 3. Equivalent emissions for several typical terminal energy.

| Terminal energy | 1kW·h electric energy efficiency | S(kg/t) | C_{SO_2}(g) | N(kg/t) | C_{NO_x}(g) |
|-----------------|---------------------------------|--------|-------------|--------|-------------|
| natural gas     | 0.114m³                          | 0.0092kg/10⁶ca 1 | 0.00090  | 1.57kg/10⁶cal | 0.151 |
| diesel          | 0.0939kg                         | 8.0    | 0.75140     | 3.21   | 0.302       |
| kerosene        | 0.0894kg                         | 1.6    | 0.14304     | 5.84   | 0.522       |
| coal            | 0.3257kg                         | 16.2   | 5.27660     | 1.88   | 0.612       |
| petrol          | 0.093kg                          | 2.4    | 0.22320     | 16.71  | 1.554       |

Potential of Electric Energy Substitution by Region

By comparing Table 1 and Table 2, we obtained the emission reduction targets by region (either \( SO_2 \) or \( NO_x \)). If the \( SO_2 \) exceeds, electric energy should be used to replace coal. The potential of electric energy substitution is calculated through emission reduction target divided sulfur dioxide conversion value for 1 unit coal (5.2766g). If the \( NO_x \) exceeds, electric energy should be used to replace petrol. The potential of electric energy substitution is calculated through emission reduction target divided nitrogen oxides conversion value for 1 unit petrol (1.554g). Then, we can calculate the potential of electric energy substitution by region shown in Table 4 based the effect of electricity emission reduction.

### Table 4. Potential of Electric Energy Substitution for environmental protection by region (10⁶kwh).

| Region | Potential of Electric Energy Substitution | Region | Potential of Electric Energy Substitution | Region | Potential of Electric Energy Substitution |
|--------|------------------------------------------|--------|------------------------------------------|--------|------------------------------------------|
| Beijing| 18.14                                    | Shandong | 503.59                                   | Chongqing | 6.37                                      |
| Tianjin| 24.25                                    | Qinghai | 0.00                                     | Sichuan | 157.19                                   |
| Hebei  | 452.87                                   | Henan  | 235.13                                   | Guizhou | 95.54                                    |
| Province      | Value   |
|--------------|---------|
| Shanxi       | 7.72    |
| Inner Mongolia| 0.00   |
| Hubei        | 96.02   |
| Tibet        | 11.10   |
| Shenxi        | 0.00    |
| Guangdong    | 0.00    |
| Shanghai     | 0.00    |
| Liaoning     | 15.95   |
| Hunan        | 107.04  |
| Jiangsu      | 199.53  |
| Jilin        | 0.00    |
| Jiangxi      | 18.84   |
| Zhejiang     | 0.00    |
| Xinjiang     | 42.77   |
| Hainan       | 0.00    |
| Anhui        | 142.93  |
| Gansu        | 0.00    |
| Fujian       | 0.00    |
| Ningxia      | 0.00    |
| Henan        | 200.00  |
| Jiangsu      | 199.53  |
| Sichuan      | 200.00  |
| Anhui        | 142.93  |
| Hunan        | 100.00  |
| Hebei        | 150.00  |
| Shandong     | 500.00  |
| Guizhou      | 100.00  |
| Gansu        | 100.00  |
| Qinghai      | 100.00  |
| Guangdong    | 100.00  |
| Guangxi      | 100.00  |
| Hainan       | 100.00  |
| Fujian       | 100.00  |
| Yunnan       | 100.00  |
| Shanghai     | 100.00  |
| Ningxia      | 100.00  |
| Inner Mongolia| 0.00   |
| Shanxi       | 0.00    |
| Jilin        | 0.00    |
| Heilongjiang | 0.00    |
| Gansu        | 0.00    |
| Xinjiang     | 100.00  |
| Jiangxi      | 100.00  |
| Zhejiang     | 100.00  |
| Hainan       | 100.00  |
| Fujian       | 100.00  |
| Yunnan       | 100.00  |
| Shanghai     | 100.00  |
| Ningxia      | 100.00  |

**Summary**

According to the potential model of electric energy substitution for environmental protection based on emission reduction targets by region, the region with the greatest potential is Shandong (more than $500\times10^9$ kw·h) and the second greatest potential is Hebei (more than $450\times10^9$ kw·h). Regions with the potential about $200\times10^9$ kw·h are Henan and Jiangsu, regions with the potential about $150\times10^9$ kw·h are Sichuan and Anhui, and regions with the potential about $100\times10^9$ kw·h are Hunan, Hubei and Guizhou. The potential of other regions are all less than $50\times10^9$ kw·h and the potential of Inner Mongolia, Shanxi, Jilin, Heilongjiang, Gansu, Qinghai, Guangdong, Guangxi, Hainan, Fujian, Yunnan, Shanghai and Ningxia are all zero.

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