# Factors analysis of $PM_{2.5}$ emission reduction in Chinese thermal power industry based on LMDI model

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**Abstract.** The Laspeyres index and its complete decomposition method are introduced to construct a complete decomposition model of $PM_{2.5}$ emission reduction in power industry. Based on the scenario analysis, the main driving factors of the emission reduction in the thermal power industry from 2007 to 2030 were studied. The results show that energy-saving technologies such as the elimination of backward production capacity and the implementation of emission reduction technologies have the greatest contribution to the management of haze in power industry, followed by the structural adjustment effect of large pressure and small structure. With the change of thermal power from the main electricity supply to the main capacity supply, the scale reduction effect will gradually appear after 2020.

## 1. Introduction

In recent years, Chinese power industry actively promote the large generating units to replace small units, referred to as "big pressure small ", and constantly optimize the power structure, the implementation of ultra-low emissions and other terminal treatment technology, all kinds of pollutants emissions declined year by year. Ultra low emissions, is refers to the power plant coal-fired boiler in the process of power operation, use a variety of pollutants efficiently coordinated removal technology integration system, making its atmospheric pollutants concentration in line with the gas emissions limit unit. By 2015, Chinese power industry, sulfur dioxide, nitrogen oxides and $PM_{2.5}$ emissions were 200 million tons, 1.8 million tons and 270,000 tons, accounting for about 10% of the country's total emissions, 10% and 12%, and compared to 2006, the reduction of emissions were 10 million tons, 6 million tons and 1.1 million tons, respectively. Assessing the actual effect and contribution of various emission reduction policies implemented in the previous, and analyzing the $PM_{2.5}$ reduction potential of power industry is of great significance to formulate the design of haze management measures in the future.

Plenty of researches on emission reduction in the power industry mainly focused on the potential of carbon emission reduction and the analysis of carbon emission reduction factors. The driving factors of emission reduction were analyzed from the power supply side, the power grid side and the user side respectively. The carbon intensity of the power industry was decomposed into energy Carbon emission coefficient, power generation structure, power generation intensity, power consumption ratio, power consumption intensity and industrial structure, and other factors [1,2,3]. The study of $PM_{2.5}$ emissions in the power industry is also limited to the impact of air quality and $PM_{2.5}$ pollution control technology [4,5], for the factors of $PM_{2.5}$ emission reduction have not been carried out in relevant research yet.

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Based on the $PM_{2.5}$ emission accounting technical specification of the Ministry of Environmental Protection, the paper establishes a $PM_{2.5}$ primary emission inventory in the power industry, and constructs the LMDI model to analyze the driving factors of $PM_{2.5}$ primary emission reduction in the power industry, and the emission reduction potential in the future.

## 2. Methodology

### *2.1. LMDI model*

Logarithmic Mean Disivia Index model (LMDI), used to decompose the $PM_{2.5}$ emission in the power industry, is applied to analyze the contribution of various emission reduction factors at different stages, and decompose it into scale effect, structure effect and technical effect. The scale effect mainly reflects the influence of the emission scale brought by the development scale of thermal power. The structural effect reflects the effect of the structural reduction caused by the change of the unit structure, for example, "big pressure small". As for technical effect, the change of coal consumption of the unit power generation reflects energy-saving technical effect, and the change of unit power generation $PM_{2.5}$ emissions reflects as the emission reduction technical effect[6,7,8].

Eq. 1 shows the formula of $PM_{2.5}$ primary emissions in electric power industry, in which, "PM" donates $PM_{2.5}$ primary emissions (ten thousand tons); "PG" donates the total power generation capacity of thermal power (hundred million kwh); "$PG_i$" donates the power generating share of units "i" in thermal power (%); "$E_i$" donates the energy consumption of units "i" (ten thousand tons); "$PM_i$" donates the $PM_{2.5}$ emissions of thermal power unit "i" (ten thousand tons).

$$PM=\sum_{i=1}^{n}\mathrm{E}_i\times\mathrm{r}_j=\sum_{i=1}^{n}PG\times\frac{PG_i}{PG}\times\frac{E_i}{PG_i}\times\frac{PM_i}{E_i}. \tag{1}$$

The formula in Eq. 2 is derived from the variety of $PM_{2.5}$ primary emissions in thermal power industry. Among them, "$\Delta PM^{PG}$", "$\Delta PM^{PGI}$", "$\Delta PM^{EI}$", "$\Delta PM^{PEF}$" represents the contribution of thermal power generation scale change, thermal power plant structure change, energy saving technology change and emission reduction technology to $PM_{2.5}$ emission reduction in power industry respectively.

$$\Delta PM_t=(\mathrm{PM})_0-(\mathrm{PM})_t=\Delta\mathrm{PM}_{PG}+\Delta\mathrm{PM}_{PGI}+\Delta\mathrm{PM}_{EI}+\Delta\mathrm{PM}_{PEF}. \tag{2}$$

According to the consistency of the form and multiplication in LMDI decomposition model, the present study uses the additive LMDI decomposition method to calculate the contribution value and degree of $PM_{2.5}$ emission change. Thus, set the power industry $PM_{2.5}$ emissions for "$PM_0$" in base period, the $PM_{2.5}$ emission for "$PM_t$" in the T phase, and the change of $PM_{2.5}$ in the T phase relative to the base period can be expressed as Eq. 2 and Eq. 3.

$$\Delta PM_t=(\mathrm{PM})_t-(\mathrm{PM})_{t\text{-}1}=\Delta\mathrm{PM}_t^{PG}+\Delta\mathrm{PM}_t^{PGI}+\Delta\mathrm{PM}_t^{EI}+\Delta\mathrm{PM}_t^{PEF} \tag{3}$$

As for scale effect, structural effect, energy saving and emission reduction technical effect of thermal power, Table.1 presents the calculating method of their contribution value and degree, respectively.

**Table1.** Calculating formula of the factors' contribution value and degree.

| Factors | contribution value | contribution degree |
|---|---|---|
| **scale effect** | $\Delta PM_{\mathrm{t}}^{PG}=\sum_{i=1}^{\mathrm{n}}\frac{PM_i^t-PM_i^{t-1}}{\ln\left(PM_i^t\right)-\ln\left(PM_i^{t-1}\right)}\times\ln\left(\frac{PG^{\mathrm{t}}}{PG^{\mathrm{t-1}}}\right)$ | $\eta_{\mathrm{t}}^{PG}=\frac{\Delta PM_{\mathrm{t}}^{PG}}{\Delta PM_t}$ |
| **structural effect** | $\Delta PM_{\mathrm{t}}^{PGI}=\sum_{i=1}^{\mathrm{n}}\left[\frac{PM_i^t-PM_i^{t-1}}{\ln\left(PM_i^t\right)-\ln\left(PM_i^{t-1}\right)}\times\ln\left(\frac{PGI_i^t}{PGI_i^{t-1}}\right)\right]$ | $\eta_{\mathrm{t}}^{PGI}=\frac{\Delta PM_{\mathrm{t}}^{PGI}}{\Delta PM_t}$ |
| **energy saving technical effect** | $\Delta PM_{\mathrm{t}}^{EI}=\sum_{i=1}^{\mathrm{n}}\left[\frac{PM_i^t-PM_i^{t-1}}{\ln\left(PM_i^t\right)-\ln\left(PM_i^{t-1}\right)}\times\ln\left(\frac{EI_i^t}{EI_i^{t-1}}\right)\right]$ | $\eta_{\mathrm{t}}^{EI}=\frac{\Delta PM_{\mathrm{t}}^{EI}}{\Delta PM_t}$ |
| **emission reduction technical effect** | $\Delta PM_{\mathrm{t}}^{PEF}=\sum_{i=1}^{\mathrm{n}}\left[\frac{PM_i^t-PM_i^{t-1}}{\ln\left(PM_i^t\right)-\ln\left(PM_i^{t-1}\right)}\times\ln\left(\frac{PEF_i^t}{PEF_i^{t-1}}\right)\right]$ | $\eta_{\mathrm{t}}^{PEF}=\frac{\Delta PM_{\mathrm{t}}^{PEF}}{\Delta PM_t}$ |

*2.2. Scenario design*

Optimization of structural adjustment in electric power industry and discharge end control measures are crucial means to achieve $PM_{2.5}$ emission reduction, separately corresponding to source control and end control. While, in the future, the elimination of backward production capacity and production equipment " big pressure small " and so on are considered to be the mainly preferred measures in coal-fired power plant structure adjustment. Similarly, ultra-low emissions measures as we all know are the major end control measures to improve the removal efficiency of $PM_{2.5}$, for instance, utilizing efficient dust removal facilities to achieve ultra-low emissions, See Table 2.

As for "big pressure small" measures, there are several policies carried out by government, such as the "coal-fired energy-saving emission reduction and transformation of the action plan (2014-2020)". According to the planning requirements, the following types of thermal power units need to be acceleratory eliminated: (1) conventional small thermal power unit with single capacity below 50,000 kilowatts, and oil-fired boilers and generating units for electricity; (2) within large power grid coverage, conventional small coal-fired power units with single capacity below 100,000 kilowatts, and single capacity below 200,000 kilowatts but full design life cycle, as well as the conventional coal-fired power units without the heating transformation; (3) before 2020, strive to eliminate the thermal power units with “High emissions, low technology”, named backward capacity, more than 10 million kilowatts.

As for energy-saving transformation, the new coal-fired power generation project (including projects that have been included in the national thermal power construction plan and have the conditions for changing the selection of the unit) applies 60,000 kilowatts and above ultra-supercritical units in principle. The power supply coal consumption for wet or air cooling unit with 100,000 kilowatts capacity should be no higher than 282 or 299 (g/kWh),while with 60,000 kilowatts capacity should be no higher than 285 or 302 (g/kWh). For heating units with capacity above 300,000 kilowatts supercritical parameters should be used, and for circulating fluidized bed low calorific value coal generating units, whose power supply coal consumption for wet or air cooling unit with 300,000 kilowatts capacity should be no higher than 310 or 327 (g/kWh), while with 600,000 kilowatts capacity should be no higher than 303 or 320 (g/kWh).

As for ultra-low emission transformation, based on the "full implementation of coal-fired power plant ultra-low emissions and energy-saving work program", by 2020, the ultra-low emissions and energy-saving coal-fired units would be completed, so that per kilowatt-hour average coal consumption for all active power plants and new coal plant would be less than 310 and 300 grams. With regard to coal-fired units that technical level less than the national standard or failure to meet the relevant mandatory requirements, they should be resolutely eliminated to shut down. The program also stipulates the eastern and central regions to reach the standard advance to 2017 and 2018.

**Table 2.** Scenario design

| | Benchmark scenario | | High scenario | |
|---|---|---|---|---|
| | **2020** | **2030** | **2020** | **2030** |
| **"big pressure small"** | Shut down small thermal power capacity 20 million kilowatts | Shut down small thermal power capacity 40 million kilowatts | Shut down small thermal power capacity 50 million kilowatts | Shut down small thermal power capacity 150 million kilowatts |
| **Emission reduction technology** | In the Beijing-Tianjin-Hebei / Yangtze River Delta and the Pearl River Delta region to implement ultra-low emissions, other areas strictly enforce GB13224-2011; Beijing-Tianjin-Hebei and other areas of dust emissions performance 0.075 g / kWh; other areas 0.09 g / kWh | In the national coal-fired power plants to implement ultra-low emissions; smoke emissions performance 0.05 g / kWh | In the national coal-fired power plants to implement ultra-low emissions; smoke emissions performance 0.05 g / kWh | In the national coal-fired power plants to implement ultra-low emissions; soot emissions performance 0.035 g / kWh |

## 3. Empirical analysis

### *3.1. Decomposition result of emission reduction factors in 2007-2015*

From the model decomposition results, from 2007 to 2015, due to the development of thermal power has been expanding, Figure1 shows that thermal power generation capacity continues to rise. Therefore, in the present process of pollutant emission reduction, scale effect is basically not exist. From the factor decomposition results, energy-saving emission reduction technology on the PM2.5 primary emission reduction of power industry presents the largest contribution rate of 59% or more; followed by structural adjustment caused by “big pressure small” and emission reduction contribution caused by energy-saving technology.

From the cumulative point of view, contribution of emission reduction, since "Eleventh Five-Year", the cumulative reduction of PM2.5 primary emission in power industry have been about 1 million tons, including contribution of dust and other emission reduction technology of about 1.3 million tons, energy-saving technology and structure adjustment of thermal power unit of about 0.1 million tons each; however, due to the expansion scale of the thermal power development, making the pollutant emissions increased by about 0.5 million tons, as shown in Figure 2.

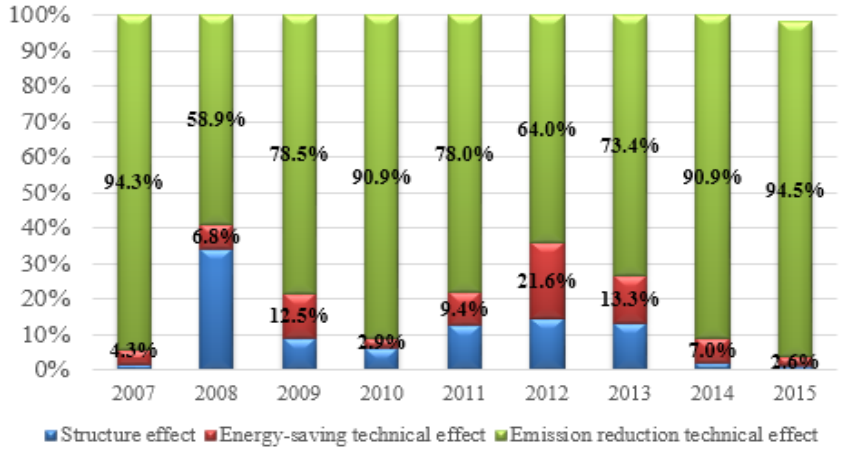



**Figure 1.** Factors’ Contributions Percent of $PM_{2.5}$ Primary Emission Reduction in 2007 – 2015

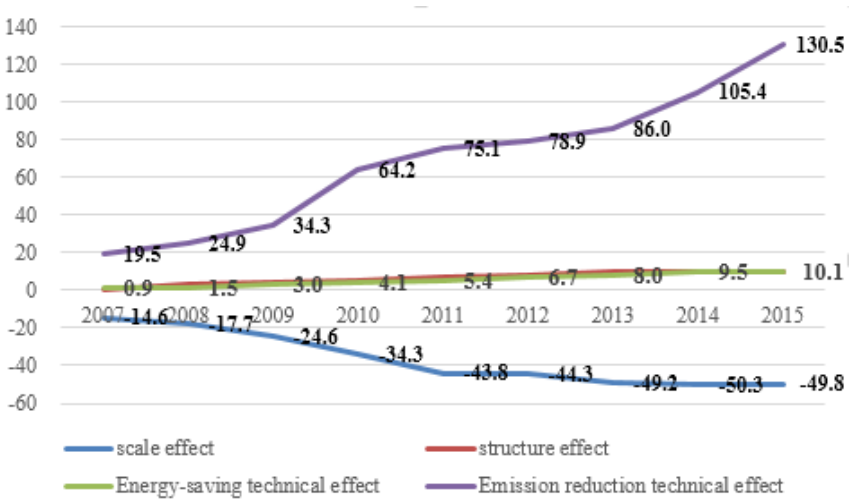



**Figure 2.** Factors' Cumulative Contributions of PM2.5 Primary Emission Reduction in 2007 -2015.

*3.2. Decomposition result of emission reduction factors in 2020 and 2030*

Based on 2015, as shown in Figure.3, this study firstly establish a list of emissions; secondly, according to scenario scenarios, target emissions are projected for the target year (2020 and 2030) scenarios. Compared with the emission situation of the power industry in 2015, based on the emission levels of different scenarios in 2020 and 2030, the LMDI decomposition model are also used to analyze the emission reduction factors in the future years.

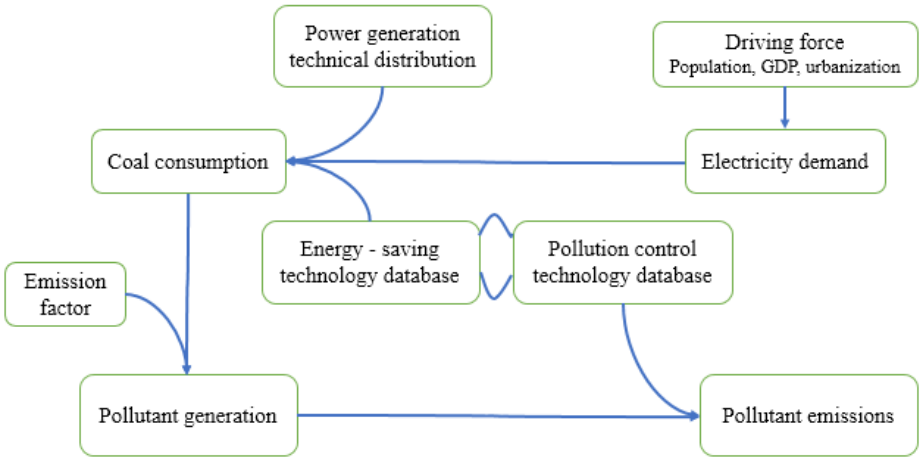



**Figure3.** Model framework of pollutant emission forecasting in different scenarios.

The results show that, with the function transformation of thermal power from main electricity supply to capacity supply, the effect of emission reduction will gradually appear after 2020. In the high scenario, thermal power industry $PM_{2.5}$ primary emission reduction will reach 94,000 tons in 2020 and 106,000 tons in 2030, of which, the contribution degree of scale effect will reach 5.9% and 19.3%, structural effect contribution degree of 6.2% and 4.1%, technical effect contribution degree of 87.5 % and 76.6% respectively, as shown in Table 3.

**Table 3**. Various factors' contributions of $PM_{2.5}$ reduction in 2020 and 2030 (compared to 2015).

| | | Scale effect | Structural effect | Energy-saving technical effect | Emission reduction technical effect | Comprehensive contribution degree |
|---|---|---|---|---|---|---|
| **2020** | Benchmark scenario | 0.0% | 2.3% | 8.4% | 89.3% | 100% |
| | High scenario | 5.9% | 6.2% | 6.8% | 81.1% | 100% |
| **2030** | Benchmark scenario | 12.7% | 9.9% | 8.5% | 69.0% | 100% |
| | High scenario | 19.3% | 4.1% | 6.3% | 70.3% | 100% |

Regarding to the thermal power scale effect, in the benchmark scenario of 2020, it has not yet appeared; whereas, as Figure.4 shown, in high scenario of 2020 and 2030, its emission reduction will reach7,800,000 tons and 104,000 tons, of which the contribution degree of scale effect, structural effect and technical effect is 12.7%, 9.9% and 76.8%, respectively.

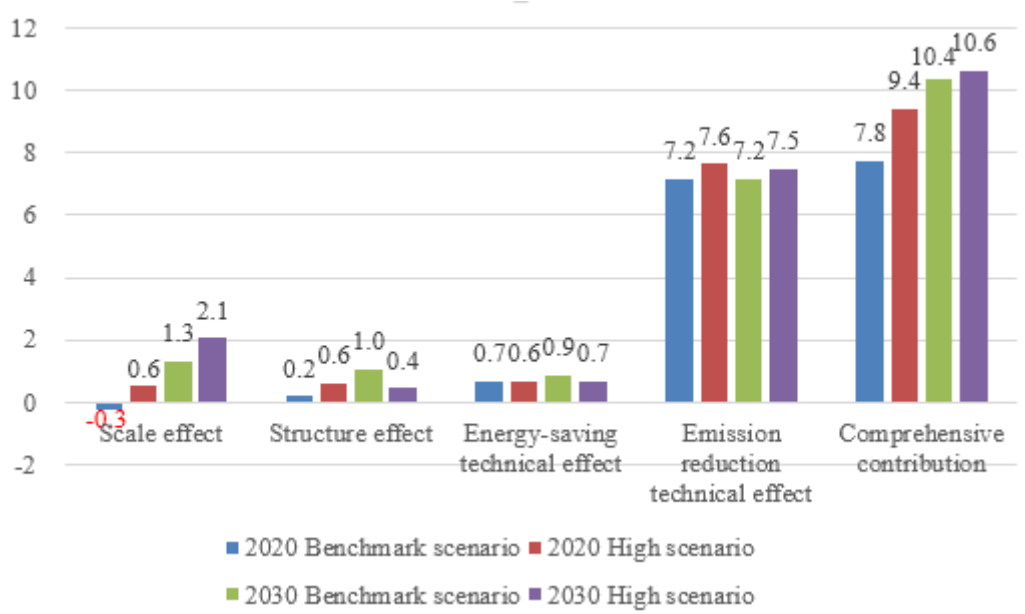



**Figure 4**. Contribution values for various factors in 2020 and 2030 (compared to 2015).

## 4. Summary

Since "Eleventh Five-Year", the PM2.5 primary emission reduction in thermal power industry mainly dominated by the end of the technology-based emission reduction, followed by structural adjustment. With the modulation of national thermal power function, the scale effect will be shown in 2020. During the "Thirteen five" period, there still has been a large space for emission reduction, which the implementation of ultra-low emission will contribute to more than 80%. With the upgrading of power structure adjustment and technological transformation is close to the level of developed countries, after 2020, the emission reduction space will tend to saturation. Meanwhile, within the framework of existing mechanism policies and technical conditions in 2030, the power industry emission reductions would basically reach the ceiling.

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