Typical calculation and analysis of carbon emissions in thermal power plants

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Abstract. On December 19, 2017, the national development and reform commission issued the national carbon emissions trading market construction plan (power generation industry), which officially launched the construction process of the carbon emissions trading market. The plan promotes a phased advance in carbon market construction, taking the power industry with a large carbon footprint as a breakthrough, so it is extremely urgent for power generation plants to master their carbon emissions. Taking a coal power plant as an example, the paper introduces the calculation process of carbon emissions, and comes to the fuel activity level, fuel emissions factor and carbon emissions data of the power plant. Power plants can master their carbon emissions according to this paper, increase knowledge in the field of carbon reserves, and make the plant be familiar with calculation method based on the power industry carbon emissions data, which can help power plants positioning accurately in the upcoming carbon emissions trading market.

1. Introduction
Since 2006, China's carbon dioxide emissions have become the world's largest, with huge pressure on carbon emissions and carbon emissions reduction. The construction of the carbon emissions trading market began in 2011, and the first carbon emissions trading was carried out in 2013. On September 25, 2015, China and the United States jointly issued the joint statement on climate change. Germanwatch, such as the European three independent institutions held in Bonn, Germany, on December 15, 2017 the United Nations framework convention on climate change of the 23rd issued a report on the conference of the parties, praised the Chinese 'on the completed more than expected in 2030 target orbit'[1].

On December 19, 2017, the national development and reform commission issued by the national carbon emissions trading market construction scheme (power generation)[2-4], officially launched the construction process of carbon emissions trading market, this marks China's carbon emissions trading system completed the overall design and officially launched. The scheme has three main systems for national carbon market construction: first, carbon emissions monitoring, reporting and verification system; Second, the quota management system of key emitters; Third, the relevant system of market transaction. At the same time, the construction of four supporting systems, namely, carbon emissions data reporting system, carbon emissions right registration system, carbon emissions trading system and settlement system, is also carried out. Accurate accounting of carbon emissions is the basis of accurate positioning in future carbon emissions trading. At present, coal-fired power plants are still in the
learning stage for the calculation of carbon emissions, and it is urgent to master their own carbon emissions.

To make plants take hold of the situation in terms of their carbon emissions, increase carbon emissions in the field of knowledge reserves, make the plant familiar with and master the power industry carbon emissions data calculation method, based on a coal-fired power plant as an example, the calculation process of carbon emissions is introduced in detail.

2. Accounting methods
This paper takes a coal power plant as the research object, and the specific scope includes: 1) CO\textsubscript{2} produced by burning fossil fuel; 2) CO\textsubscript{2} in desulfurization process; 3) net purchase of CO\textsubscript{2} produced by electricity. Among them, the CO\textsubscript{2} caused by domestic consumption cannot be accounted for.

According to the power generation plants in China in greenhouse gas emissions accounting methods and reporting guidelines (trial) (hereinafter referred to as the accounting guidelines), power generation company’s greenhouse gas emissions is equal to the emissions of fossil fuel combustion emissions, desulfurization process and the sum of net buying power emissions, according to the Eq. (1) [5, 6]:

\[
G=G_R+G_S+G_D
\]

In (1): G is the total amount of greenhouse gas emissions; \(G_R\) is the CO\textsubscript{2} emissions from fossil fuel combustion in the plant; \(G_S\) is the CO\textsubscript{2} emission from the decomposition of the desulfurization agent in the plant; \(G_D\) is the CO\textsubscript{2} emission from the net purchased electricity of the plant, the unit is CO\textsubscript{2} equivalent.

2.1 Fossil fuel combustion emissions.
Fossil fuel consumption is mainly made up of coal, auxiliary fuel, and mobile facilities with diesel oil and mobile facilities. In Eq. (2) [5, 6]:

\[
G_R=G_{RM}+G_{BB}+G_{RC}+G_{RQ}
\]

In (2): \(G_{RM}\) is the CO\textsubscript{2} emissions produced by coal combustion; \(G_{BB}\) is the CO\textsubscript{2} emissions produced by auxiliary fuel combustion; \(G_{RC}\) produces CO\textsubscript{2} emissions from diesel combustion for mobile devices; \(G_{RQ}\) is the amount of CO\textsubscript{2} emitted by gasoline combustion for mobile devices, and the unit is tCO\textsubscript{2} equivalent.

The CO\textsubscript{2} emissions from the combustion of the i fossil fuel are calculated by Eq. (3) [7]:

\[
G_R=\sum D_i \times F_i
\]

In (3): \(D_i\) is the activity level of the i fossil fuel (TJ), which is expressed by the calorific value; \(F_i\) is the i fossil fuel emissions factor (tCO\textsubscript{2}• t\textsuperscript{-1}); i is the fossil fuel type.

The activity level \(D_i\) of the i fossil fuel is calculated by Eq. (4):

\[
D_i=C_i \times CV_i \times 10^5
\]

In (4): \(C_i\) is the consumption of the i fossil fuel (t); \(CV_i\) is the average low calorific value of the i fossil fuel (KJ•kg\textsuperscript{-1});

The i fossil fuel emissions factor \(F_i\) is calculated by Eq. (5):

\[
F_i=DC_i \times DF_i \times 44/12
\]

In (5): \(DC_i\) is the carbon content of the unit calorific value of the i fossil fuel (tC• t\textsuperscript{-1}); \(DF_i\) is the carbon oxidation rate of the i fossil fuel (%); 44/12 is the ratio of carbon dioxide to carbon. The emissions factor is the coefficient representing the emissions of greenhouse gases in the activity level of the unit, indicating the representative emissions rate of a certain activity level under the given operating conditions.

2.2 Emissions of CO\textsubscript{2} from desulfurization process.
The CO\textsubscript{2} emission of desulfurization process can be calculated by multiplying the consumption of carbonate by the emission factor, and the Eq. (6) is calculated as follows:

\[
G_S=\sum CA_k \times SF_k
\]
In (6): $CA_k$ is the consumption of carbonate (t) in the $k$ desulfurizer; $SF_k$ is the carbon dioxide emission factor ($tCO_2•t^{-1}$) in the $k$ desulfurizer; $k$ is the type of desulfurizer.

The consumption of carbonate in desulfurizer is calculated by Eq. (7):

$$CA_k = \sum_m CB_{k,m} \times CI_k$$  \hspace{1cm} (7)

In (7): $CB_{k,m}$ is the consumption of desulfurizer during the whole year (t); $CI_k$ is the carbonate content in desulfurizer; $m$ expresses month.

The emission factor of desulfurization process is calculated by Eq. (8):

$$SF_k = SF_k,\times ZH$$  \hspace{1cm} (8)

In (8): $SF_k,\times$ is the emission factor of desulfurization process ($tCO_2•t^{-1}$) in the process of complete transformation; $ZH$ is the conversion rate (%).

### 2.3 $CO_2$ emissions generated by et purchase electricity.

For net purchase of $CO_2$ emissions generated by electric power, the net purchase quantity is multiplied by the average power supply emission factor of the regional power grid, and the calculation is based on Eq. (9):

$$GD = JD_D \times JF_D$$  \hspace{1cm} (9)

In (9): $JD_D$ is the net purchase power (MWh) of the plant; $JF_D$ is the average power supply emission factor ($tCO_2•MWh^{-1}$) for the regional grid.

### 3. The calculation of carbon emissions.

#### 3.1 Coal

Plant every day to boiling coal sampling and industrial analysis, record its low calorific value and so on analysis results, according to the calculated boiling coal volume weighted average daily average low calorific value coal, calculated according to the type (4) the activities of the coal level as shown in Table 1.

**Table 1** Coal activity levels

|       | 2011  | 2012  | 2013  | 2014  |
|-------|-------|-------|-------|-------|
| Annual coal consumption /t | 2472315 | 2067752 | 2072035 | 2017605 |
| The annual average low heating value of coal. /KJ•kg⁻¹ | 16862 | 17302 | 17823 | 18322 |
| The level of activity of coal burning. /TJ | 41688.18 | 35776.25 | 36929.88 | 36966.56 |

According to the accounting guide, the plant should collect and shrink the samples every day, and the final day of each month shall be mixed with the shrink samples obtained on a daily basis to measure the carbon content of the elements. In 2011-2014, the power plant did not measure the carbon content of the elements of coal burning, and the carbon content of the elements of coal burning could be calculated according to the Eq. (10).

$$C_d = 35.411 - 0.341A_d + 0.199V_d + 0.412S_d + 0.632Q_{gr,d}$$  \hspace{1cm} (10)

In (10): in the $A_d$, $V_d$, $S_d$ respectively monthly average dry base unit charging coal ash content, volatile matter, total sulphur content (%), $Q_{gr,d}$ unit for boiling coal monthly average dry base high calorific value, KJ•g⁻¹). The average monthly high calorific value is calculated according to the daily high calorific value, and the weight is the daily coal consumption.

The carbon content of the unit calorific value is the element carbon content divided by the corresponding low calorific value. Due to the large amount of data, the calculation results are only listed in Table 2.

**Table 2** The unit value of carbon content in coal average year

|       | 2011  | 2012  | 2013  | 2014  |
|-------|-------|-------|-------|-------|
| The annual average calorific value of coal is carbon. /tC•TJ⁻¹ | 27.58 | 27.10 | 26.91 | 26.84 |

The carbon oxidation rate of coal-fired units is calculated by Eq. (11):

$$OF_A = 1 - [(G_f \times C_A + G_i \times C_i \times \eta_c) \times 10^6] / (FC_{Hi} \times NCV_{Hi} \times CC_{Hi})$$  \hspace{1cm} (11)
In (11): $OF_M$ is the carbon oxidation rate of coal (%); $G_Z$ is the annual slag yield (t); $C_Z$ is the average carbon content of slag (%); $G_H$ is the annual fly ash yield (t); $C_H$ is the average carbon content of fly ash (%); $FC_M$ is the consumption of coal (t); $NCV_M$ is the average low calorific value of coal (KJ•kg⁻¹); $CC_M$ is the calorific value of coal (tC•TJ⁻¹).

The output of slag and fly ash are measured by the actual quantity. The efficiency of the electrostatic precipitator adopts the data provided by the manufacturer. The carbon content of slag and fly ash is calculated according to the measured value of each sample in the month. The test of fly ash and cinder samples followed the requirements of DL/T 567.6 fly ash and slag combustibles measurement method. According to Eq. (11), the carbon oxidation rate parameters of coal are shown in Table 3.

| Parameter of coal carbon oxidation rate |
|----------------------------------------|
| $G_Z$/t | $C_Z$% | $G_H$/t | $C_H$% | $\eta_C$% | $OF_M$% |
| 2011    | 3548.47 | 0.74    | 31936.25 | 0.34       | 99.93   | 99.67   |
| 2012    | 2686.72 | 0.51    | 24180.51 | 0.53       | 99.93   | 99.82   |
| 2013    | 2248.22 | 1.11    | 20233.96 | 0.89       | 99.93   | 99.69   |
| 2014    | 2548.04 | 1.15    | 22932.37 | 0.91       | 99.93   | 99.63   |

According to Eq. (5) of Table 2 and Table 3, coal emission factors are calculated as shown in Table 4:

| Coal Emission coefficient |
|---------------------------|
| year | 2011 | 2012 | 2013 | 2014 |
|--------------------------------|
| The annual average calorific value of coal. /t$C$•TJ⁻¹ | 27.58 | 27.10 | 26.91 | 26.84 |
| Average annual carbon oxidation rate of coal. /% | 99.67 | 99.82 | 99.69 | 99.63 |
| Coal burning emission factors. /t$CO_2$•TJ⁻¹ | 100.79 | 99.19 | 98.38 | 98.03 |

The data in Table 1 and Table 4 are calculated according to Eq. (3), and the $CO_2$ emissions generated by coal burning are calculated as shown in Table 5:

| Emissions from burning of coal |
|-------------------------------|
| year | 2011 | 2012 | 2013 | 2014 |
|--------------------------------|
| The level of activity of coal burning. /TJ | 41688.18 | 35776.25 | 36929.88 | 36966.56 |
| Coal burning emission factors. /t$CO_2$•TJ⁻¹ | 100.79 | 99.19 | 98.38 | 98.03 |
| $CO_2$ emissions from burning coal. /t | 4201874.14 | 3548567.28 | 3633137.70 | 3623866.45 |

3.2 Auxiliary fuel oil

The auxiliary fuel consumption data of the power plant is derived from the production monthly report data. The auxiliary fuel is diesel, and the low calorific value is provided by the default value of 42652kJ/kg in the accounting guide. According to Eq. (4), the level of auxiliary fuel activity in power plant is shown in Table 6.

| Auxiliary fuel activity levels |
|-------------------------------|
| year | 2011 | 2012 | 2013 | 2014 |
|--------------------------------|
| Auxiliary fuel low heat. /KJ•kg⁻¹ | 42652 | 42652 | 42652 | 42652 |
| Auxiliary fuel consumption per year. /t | 492.11 | 416.12 | 254.6 | 193.6 |
| Auxiliary fuel activity level. /TJ | 20.99 | 17.75 | 10.86 | 8.26 |

The unit calorific value of fuel oil and the carbon oxidation rate are the default values provided by the accounting guide. According to Eq. (5), the fuel emission factors are calculated as shown in Table 7:

| Fuel Emission coefficient |
|---------------------------|
| auxiliary fuel | diesel | gasoline |
The annual average unit calorific value is carbon content. / tC•TJ⁻¹

Average annual carbon oxidation rate. /%  

Emission factor / tCO₂•TJ⁻¹

According to the data in Table 6 and Table 7, the CO₂ emissions generated by auxiliary fuel combustion are calculated as shown in Table 8:

| Table 8 Emissions from burning of auxiliary fuel |
|-----------------------------------------------|
| Year  | 2011 | 2012 | 2013 | 2014 |
|-------|------|------|------|------|
| Auxiliary fuel activity level. /TJ | 20.99 | 17.75 | 10.86 | 8.26 |
| Auxiliary fuel emission factor. /tCO₂•TJ⁻¹ | 72.59 | 72.59 | 72.59 | 72.59 |
| Auxiliary fuel combustion of CO₂ emissions. /t | 1523.63 | 1288.35 | 788.27 | 599.41 |

3.3 Mobile source oil.

Plant mobile facilities including production car diesel oil consumption and public transport gasoline consumption, diesel and gasoline low calorific value, unit calorific value carbon content, carbon oxidation rate all use the default value of data in accounting guidelines. According to Eq. (3) and (4), the activity level and CO₂ emissions of mobile source are calculated as shown in Table 9.

| Table 9 Mobile source oil activity level and CO₂ emissions. |
|-------------------------------------------------------------|
| Year  | 2011 | 2012 | 2013 | 2014 |
|-------|------|------|------|------|
| Diesel annual consumption /t | 109.67 | 122.35 | 120.93 | 79.15 |
| Annual gasoline consumption /t | 61.85 | 65.76 | 71.68 | 67.63 |
| Diesel average low heat value. /KJ•kg⁻¹ | 42652 |
| Average low heating value for gasoline. /KJ•kg⁻¹ | 43070 |
| Diesel activity level /TJ | 4.68 | 5.22 | 5.16 | 3.38 |
| Level of gasoline activity / TJ | 2.66 | 2.83 | 3.09 | 2.91 |
| Diesel emission factorGF /tCO₂•TJ⁻¹ | 72.59 | 72.59 | 72.59 | 72.59 |
| Gasoline emission factorGF /tCO₂•TJ⁻¹ | 67.91 | 67.91 | 67.91 | 67.91 |
| Diesel emission /tCO₂ | 339.72 | 378.92 | 374.56 | 245.35 |
| Gasoline emission /tCO₂ | 180.64 | 192.19 | 209.84 | 197.62 |
| Total emission /tCO₂ | 520.36 | 571.11 | 584.41 | 442.97 |

3.4 Data collection and calculation of activity level of desulfurization process.

The main activity level data of desulfurization process is the consumption of desulfurizer, and the consumption data of desulfurizer in this power plant is derived from the statistics of limestone consumption. The carbonate content in the desulfurizer is the default value provided in the accounting guide. The activity level of desulfurization process was calculated by Eq. (7). Plants adopt limestone as desulfurizer, desulfurization process carbonate decomposition produces CO₂. According to the accounting guide, the default value of the limestone conversion rate is 100%, and the default value of the desulfurization process is 0.44 tCO₂•t⁻¹. According to Eq. (6), the CO₂ emission produced by desulfurization process is shown in Table 10:

| Table 10 Desulfurization process activity levels |
|-----------------------------------------------|
| Year  | 2011 | 2012 | 2013 | 2014 |
|-------|------|------|------|------|
| The annual consumption of desulfurizer. /t | 34917.14 | 49705.14 | 39451.22 | 43340.1 |
| The carbonate content in desulfurizer. /% | 90 | 90 | 90 | 90 |
| Activity level of desulfurizer. /TJ | 31425.43 | 44734.63 | 35506.1 | 39006.09 |
3.5 Net purchasing power activity level data collection.
Net purchase of the activity level of the use of electricity is net purchase of electricity, net purchase of electricity data from the production monthly report data. The plant is located in Shanxi Province, and the net purchase of electricity comes from the north China grid. For power emission factors, the average CO$_2$ emission factor of China's regional grid is determined by the national development and reform commission (NDRC). According to Eq. (9), the CO$_2$ emission generated by net purchase of power generation is shown in Table 11.

| Year       | 2011   | 2012   | 2013    | 2014    |
|------------|--------|--------|---------|---------|
| CO$_2$ emissions/t | 4201874.14 | 3548567.28 | 3633137.70 | 3623866.45 |
| The auxiliary fuel  | 1523.63     | 1288.35      | 788.27     | 599.41      |
| Mobile oil          | 520.36       | 571.11       | 584.41      | 442.97      |
| The desulfurization process | 13827.19     | 19683.24      | 15622.68     | 17162.68     |
| Net purchase of power emissions/t | 630.33     | 1704.93      | 629.86     | 1293.06     |
| Plant total         | 4218375.65   | 3571814.91   | 3650762.92  | 3643364.57  |

3.6 Summary of CO$_2$ emissions.
The data in Table 5, Table 8, Table 9, Table 10 and Table 11 are summarized to calculate the total CO$_2$ emission summary as shown in Table 12:

| CO$_2$ emissions/t | 2011   | 2012   | 2013    | 2014    |
|--------------------|--------|--------|---------|---------|
| coal               | 4201874.14 | 3548567.28 | 3633137.70 | 3623866.45 |
| The auxiliary fuel  | 1523.63     | 1288.35      | 788.27     | 599.41      |
| Mobile oil          | 520.36       | 571.11       | 584.41      | 442.97      |
| The desulfurization process | 13827.19     | 19683.24      | 15622.68     | 17162.68     |
| Net purchase of electricity | 630.33     | 1704.93      | 629.86     | 1293.06     |
| Plant total         | 4218375.65   | 3571814.91   | 3650762.92  | 3643364.57  |

As can be seen from Table 12, the CO$_2$ emissions of the research objects are mainly generated from the combustion process of fossil fuels, accounting for 99% of the total CO$_2$ emissions. The research object of power plant overall high CO$_2$ emissions, in order to reduce the unit power supply of CO$_2$ emission value, also need to modify operation equipment, of which the main object of governance can be put in the unit ontology, desulfurization equipment, auxiliary fuel in three aspects.

4. Conclusions
The implementation of national carbon emissions trading market construction plan (power generation industry) will make the electric power plants which have high level management and low emissions per unit product to obtain the corresponding quota increased, to have competitive advantages, and so gain more and more market space opportunity. On the contrary, plants with low management level and low technical equipment may be at a disadvantage in the future market competition. Therefore, power generation plants should clarify the carbon emissions situation on their own as soon as possible and formulate corresponding measures to occupy a favourable position in the carbon emission trading market. Power plants may refer to this paper, according to the operation to obtain the more accurate carbon emissions; we suggest using months or weeks for the unit of time in the actual data collection and calculations. Because time unit is too small and data is too big, the unit of time will affect the calculation accuracy.

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