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The Overview for the Greenhouse-gas Emission Characteristics and Intensity in the Electric Power Industry

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Abstract

China has ranked the first in carbon emission in the world, and the electric power industry is listed as the predominant field in all industries, which causes the biggest environmental pollution. It is useful to identify the carbon emission sources in electric power industry in China and concludes the possible ways to calculate the greenhouse gases emissions. It will be the base to set up the possible estimation model for emission, and help to analyze the methods to reduce the emission.

Key words: Electric Power Industry; Greenhouse-gas Emission; Emission Properties; Emission Intensity

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INTRODUCTION

Nowadays, as the consensus problem of developing the "low-carbon economy" around the world, the question that how to reduce the greenhouse gas emissions (GHG) has become a focused problem, especially in china. The statistics issued by IEA (International Energy Agency) shows that China ranks first globally in national carbon emissions from 2010, and in China the electric power industry contributes 42% to the total carbon emissions. Thus how to identify the characteristics of carbon emissions, how to explore these factors in power industry, how to calculate these emissions and study the influencing factors, are particular significant now.

1. CHARACTERISTICS ON THE GREENHOUSE GAS EMMISSIONS SOURCES IN THE ELECTRIC POWER INDUSTRY

It is well known that the climate change caused by Greenhouse gas (GHG) emissions has become one of the major environmental problems today. According to the signed Kyoto Protocol, which came into effect on 16 February 2005, it has defined the main greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydro fluorocarbons (HFCs), per fluorocarbons (PFCs), and sulfur hexafluoride (SF_6), etc.

In electric power industry, there are three greenhouse gases observed easily. They are CO_2, methane, and nitrous oxide. Comparing with these three gases, the others such as halogenated gas emissions can generally be negligible, but in other industries they produced and might exist in the atmosphere for a long time to produce a strong radioactive forcing effect.

In the estimation amount of greenhouse gas emissions, these six Kyoto gases will be identified from their sources respectively, calculated on their amount in the scale of time and space, and then multiplied with the global-warming potential (GWP) into a single potential value. The GWP is to compare how much heat can be trapped by the amount of greenhouse gas in question to the amount of similar mass of carbon dioxide. The GWP is calculated over a specific time interval, commonly 20, 100 or 500 years. In this way, the GWP is always expressed as a factor of carbon dioxide, such as the 20 year GWP of methane is 72, which means that if the same mass of methane and carbon dioxide were introduced into the atmosphere, that methane will trap 72 times more heat than the carbon dioxide over the next 20 years.

1.1 Identification of Greenhouse-gas Emissions Sources for the Electric Power Industry

In a typical electricity power generating processes, there consists of exploration, construction, production, transmission, distribution and sale of electricity (power supply). In the main part of the electric power industry, the scope of greenhouse gas emissions is limited to power production processes, and the other part produces greenhouse gases in relatively minor amount.

The main ways of energy production in electric power industry depend on thermal power, hydropower, nuclear power and other clean energies, such as geothermal power, wind power, solar power, tidal power, wave energy, ocean thermal power, fuel cell power, biomass power. Within which, the thermal power can be divided into coal-fired power generation, fuel power generation, gas-fired power generation (LNG), and the overall gasification combined cycle (IGCC) power generation, etc.

According to the provisions in *the 2006 IPCC Guidelines for National Greenhouse Gas Inventories emissions*[5], the main categories of emission sources are shown as following which we can identifies as the most common resources for greenhouse gases in Chinese power industry:

i) The exploration and utilization of primary energy resources;

ii) A one-time energy resources are turned into more useful forms of energy in refineries and power plants;

iii) About the fuel delivery and distribution;

iv) Fuel utilization in fixed and movable applications.

Therefore, in the preparation and reporting for greenhouse-gas inventory, the scope of the power industry energy activities mainly includes carbon dioxide and nitrous oxide from fossil fuel combustion as well as methane emissions from biomass fuels combustion. Furthermore, comparing with carbon dioxide, the two gases including nitrous oxide and methane emissions that generated by the power industry are much less in amount generated.

1.2 Analysis About the Characteristics of Greenhouse Gases Emissions in Electric Power Industry

The above identification tells that the power industry emissions of greenhouse gases (CO_2, CH_4, and N_2O) mainly are produced in the generation process of the thermal power, heating, and biomass power generation enterprises. In accordance with the different fuels, thermal power enterprises in China can be divided into three types: coal-fired power generation heating, gas-fired generation heating and fuel power generation heating enterprises. But in functions, there are two main categories in China that is related to the production for combined heat and electricity or only for electricity. Analysis of Greenhouse-gas emission characteristics of the electric power industry are shown in table 1.

Table 1
Analysis of Power Industry Emissions of Greenhouse Gases

NO.	Main Activity	producer	Types of gas	Producing process	Ways to emit
1	Electric power generation	Thermal power plant	CO_2,N_2O	Fuel combustion	In gaseous form with flue gas
2	Electric power generation	Biomass power plant	CH_4	Fuel combustion	In gaseous form with flue gas
3	Electricity and heat production	Thermal Power Plant	CO_2,N_2O	Fuel combustion	In gaseous form with flue gas

he above table shows that the thermal power enterprises produce greenhouse gases (CO_2, CH_4, N_2O) emissions continuous and stable, which is able to be monitored. The greenhouse gases are discharged in the atmosphere with the flue gas into gaseous form, and the level of CO_2 content in the flue gas varies with fossil fuel. In general, coal-fired power generation is greater than fuel-power generation in CO_2 emissions, while gas-fired generation have the lowest CO_2 emissions. One liter of gasoline, when used as a fuel, produces 2.32 kg (about 1300 liters or 1.3 cubic meters) of carbon dioxide, a greenhouse gas.

Table 2
Mass of Carbon Dioxide Emitted per Quantity of Energy for Various Fuels

Fuel name	CO_2 emitted(g/10^6 J)	Fuel name	CO_2 emitted(g/10^6 J)
Natural gas	50.3	Tires/tire derived fuel	81.26
Liquefied petroleum gas	59.76	Wood and wood waste	83.83
Propane	59.76	Coal (bituminous)	88.13
Aviation gasoline	65.78	Coal (sub-bituminous)	91.57
Automobile gasoline	67.07	Coal (lignite)	92.43
Kerosene	68.36	Petroleum coke	96.73
Fuel oil	69.22	Coal (anthracite)	97.59

2. COAL-FIRED ELECTRIC TECHNOLOGIES IN POWER INDUSTRY AND ITS EMISSIONS INTENSITY2.1 MAIN COAL-FIRED TECHNOLOGIES FOR POWER INDUSTRY

As the predominant part in Chinese power industry, the coal-fired electricity generation plants are accounted for about 80 percent of the total generating capacity. Nowadays, several technologies developed in coal related scheme has been evolving from the initial model status of diverse, small-capacity, low parameter ordinary condensing steam thermal power units (around 300 MW) to the popular model of subcritical units, and in the potential of being improved to the large-capacity, high-parameters of supercritical and ultra-supercritical units (600MW - 1000MW single unit capacity) to the more advanced, higher efficiency of IGCC units. Different kinds of coal-fired technology will cause different potential for greenhouse gas emissions. What's more, the different technologies will be combined with different possibility to improve the efficiency in power generation and reduce the greenhouse gas emissions.

i) Subcritical, supercritical and ultra-supercritical

The subcritical, the supercritical, and the ultra-supercritical units are combined with different boilers and steam generators. Generally, new boiler with steam pressure greater than critical pressure (22.064MPa) and less than 25MPa boiler is called supercritical boilers, supporting supercritical steam turbine. Ultra-supercritical boiler with steam pressure between 25~31MPa, which supports the turbine called ultra-supercritical steam turbine.

About generators, the subcritical, the supercritical and the ultra-supercritical generating units are distinguished mainly by steam pressure and temperature parameters. That is to say: subcritical, 170 ata, 535 ° C; supercritical, 240 ata, 560 ° C; and ultra-supercritical, 300 ata, 600 ° C.

There are evidences proved that the efficiency of ultra-supercritical units reach 48%, and the coal consuming reduces to 270 g/kWh, which means almost 1/3 carbon emission reduction comparing to normal coal-fired electricity generation units.

ii) CFBC and PFBC[1]

Circulating fluidized bed boiler can efficiently burn a variety of fuels; especially to low grade coal which is always contains some substantial hard to burn. Especially, excepting to CO_2, the SO_2 emission in the combustion process is also controlled by adding a desulfurizer agent, and the fluidized bed with low temperature combustion also restrains the generation of NO_2.

PFBC has similar advantages to CFBC, which will deal the fuel in pressurized fluidized bed with combustion of high-temperature flue gas that flows through the dust into the gas turbine acting, which constitutes the pressurized fluidized bed combustion combined cycle (PFBC-CC). The CFBC and PFBC will enhance the coal consuming efficiency about 10% at current technology level.

iii) IGCC

Integrated Gasification Combined Cycle is a combination of advanced coal gasification technology, which has a highly efficient combined cycle power system that integrates gasification combined cycle power generation system. It consists of two parts, namely, the coal gasification and purification section, and the gas-steam combined cycle power generation section[2].

IGCC is still in the demonstration trial phase, which is expected to reach 55% of fuel efficiency.

iv) CCS

Carbon sequestration is one of the key technologies in the combustion of fossil energy zero-emission utilization. Carbon dioxide may be captured as a pure by-product in processes related to flue gases from power generation. Carbon sequestration includes the storage part of carbon capture and storage, which refers to large-scale, permanent artificial capture and sequestration of industrially produced CO_2 using subsurface saline aquifers, reservoirs, ocean water, aging oil fields, or other carbon sinks.

There are at least three categories of carbon sequestration processes, such as biological processes, physical processes, and chemical processes[3].

Inside, the chemical processes are most popular in China. This process is known as "carbon sequestration by mineral carbonation" or mineral sequestration. In Chinese carbon sequestration model of power generation project, the process involves reacting carbon dioxide with abundantly available metal oxides–either magnesium oxide (MgO) or calcium oxide (CaO)–to form stable carbonates. These reactions are exothermic and occur naturally (e.g., the weathering of rock over geologic time periods).

- $CaO + CO_2 \rightarrow CaCO_3$
- $MgO + CO_2 \rightarrow MgCO_3$

Calcium and magnesium are found in nature typically as calcium and magnesium silicates (such as forsterite and serpentinite) and not as binary oxides. For forsterite and serpentine the reactions are:

- $Mg_2SiO_4 + 2CO_2 = 2MgCO_3 + SiO_2$
- $Mg_3Si_2O_5(OH)_4 + 3CO_2 = 3MgCO_3 + 2SiO_2 + 2H_2O$

2.2 Emission Intensity of Typical Coal Units

The efficiency, fuel consumption, and corresponding emission intensity of typical units are shown in table 2.

Table 2
Efficiency and Emission Intensity Of Typical Units

Type	Status quo	efficiency	Coal consumption(gce/kWh)	Emission intensity(gCO_2e/kWh)	Capacity in 2006 (MW)
Coal power	Null	30%	410	1138	17000
Subcritical low-end	Main mode	35%	351	976	15300
Subcritical high-end	Main mode	39%	315	876	6970
CFBC	Commercial Demonstration	40%	300	850	30
FBC	Demonstration	45%	273	759	1.5
Supercritical lower limit	Commercial	40%	307	854	3780
Supercritical ceiling	Commercial	42%	293	814	
Ultra-supercritical	Commercial Demonstration	43%	286	795	300
IGCC lower limit	Demonstration	45%	273	759	0
IGCC ceiling	Demonstration	55%	223	621	0
TOTAL		34%	364	1011	43400

Source: Analysis of typical units by Energy Development and Reform Commission

3. EMISSIONS INTENSITY CALCULATION METHOD FOR POWER INDUSTRY

3.1 Electricity Emissions Intensity Calculation Method

The power emission intensity is measured by emission per unit (tons CO_2e/kWh). In theory, all coal consumption of thermal power in China can be simply figured out by heat per standard coal and carbon emissions per heat unit. But this method is always not accurate and available for an identical power unit to calculate itself greenhouse gases emissions.

Following is the methods to demonstrate the specific CO_2 emissions intensity. As far as other related gases, such as methane or similar pollutant gases of SO_2 or NO_x.

i) Calculation way.

A certain type of fuel emission factor $COEF_{i,y}$ can be gotten through the following general formula estimation.

$$COEF_{i,y} = NCV_i \# EF_{CO2,i} \# OXID_i$$

Where,

NCV_i= the net calorific value (energy content of the fuel i per unit mass or volume);

$OXID_i$= fuel oxidation rate (see IPCC Guidelines default value of 1996 amended version 1.29);

$EF_{CO2,\ i}$= the CO_2 emission factor per unit of fuel energy i.

The local NCV_i and $EF_{CO2,\ i}$ values must be used if possible. If not available, specific state values, for example, the IPCC paradigm Guides should be better than the default value of IPCC world.

ii) After calculation

After the fuel emission coefficient (usually tCO_2e / mass or volume units) is obtained, the total emissions from coal consumption levels (unit: gce / kWh), can be gotten by the multiplication of the emission intensity of electricity and electric capacity.

iii) Formula factor analysis

Further analysis of the formula factors have been given in different researches [3], [4], [6]. In summary of these researches, we can use the different methods to reduce the difficulties in greenhouse gas emission calculation, where the baseline and project emission of the whole emission system are identical with the similar calculation principles.

Below is the discussion about the predominant factors in the $COEF_{i,y}$ calculation.

3.1.1 $COEF_{i,y}$

With the above $COEF_{i,y}$ formula, and if we have stored the related material of a plant, the determined calculation can follow the below way that the emission factor is calculated based on the net electricity generation of each power unit and an emission factor for each power unit, as follows:

$$\mathrm{EFCO}_{i,y} = \frac{\sum_m EG_{m,y} \times EF_{EL,m,y}}{\sum_m EG_{m,y}}$$

Where,

$COEF_{i,y}$ = simple CO_2 emission factor in year y (tCO_2/MWh).

$EG_{m,y}$=net quantity of electricity generated and delivered to the grid by power unit m in year y(MWh).

$EF_{EL,m,y}$= CO_2 emission factor of power unit m in year y (tCO_2/MWh).

m = all power units serving the grid in year y.

y = the relevant year as per the data vintage chosen, which is always set as the baseline year of the whole greenhouse-emission calculation.

Although the $COEF_{i,y}$ has been determined, there are some ways for the calculations methods for $FE_{EL,m,y}$ and $EG_{m,y}$ (especially for isolated power plants).

3.1.2 $EF_{EL,m,y}$

The emission factor of each power unit m can be determined in two options as follows:

• Option 1. If for a power unit m data on fuel consumption and electricity generation is available, the emission factor ($EF_{EL,m,y}$) should be determined as follows:

$$EF_{EL,m,y} = \frac{\sum_i FC_{i,m,y} \times NCV_{i,y} \times EF_{CO2,i,y}}{EG_{m,y}}$$

Where,

$EF_{EL,m,y}$ = CO_2 emission factor of power unit m in year y (tCO_2/MWh).

$FC_{i,m,y}$= amount of fossil fuel type i consumed by power unit m in year y (Mass or volume unit).

$NCV_{i,y}$= net calorific value (energy content) of fossil fuel type i in year y (GJ/mass or volume unit).

$EF_{CO2,i,y}$= CO_2 emission factor of fossil fuel type i in year y (tCO_2/GJ).

$EG_{m,y}$= net quantity of electricity generated and delivered to the grid by power unit m in year y (MWh).

m = all power units serving the grid in year y.

i = all fossil fuel types combusted in power unit m in year y.

y = the relevant year as per the data vintage chosen year.

• Option 2. If for a power unit m only data on electricity generation and the fuel types used is available, the emission factor should be determined based on the CO_2 emission factor of the fuel type used and the efficiency of the power unit, as follows:

$$EF_{EL,m,y} = \frac{EF_{CO2,m,i,y} \times 3.6}{\eta_{m,y}}$$

Where,

$EF_{EL,m,y}$= CO_2 emission factor of power unit m in year y (tCO_2/MWh).

$EF_{CO2,m,i,y}$= average CO_2 emission factor of fuel type i used in power unit m in year y(tCO_2/GJ).

$\eta_{m,y}$ = average net energy conversion efficiency of power unit m in year y (ratio).

m = all power units serving the grid in year y except low-cost/must-run power units.

y = the relevant year as per the data vintage chosen year.

3.1.3 $EG_{m,y}$

For grid power plants, $EG_{m,y}$ is easily to be calculated as the monitoring cables provided from local grid company, or the records by the monitoring gate meters.

However, for some off-grid power plants, which is seldom in big cities, it is still existed and necessary to calculate the $EG_{m,y}$.

To those off-grid plants, it can be determined as follows:

• Option 1. $EG_{m,y}$ is determined based on (sampled) data on the electricity generation of off-grid power plants around in the determined area.

• Option 2. $EG_{m,y}$ is determined based on (sampled) data on the quantity of fossil fuels combusted in the class of off-grid power plants m, as follows:

$$EG_{m,y} = \frac{\sum_i FC_{i,m,y} \times NCV_{i,y} \times \eta_{m,y}}{3.6}$$

Where,

$EG_{m,y}$= net quantity of electricity generated and delivered to the grid by power unit m in year y (MWh).

$FC_{i,m,y}$= amount of fossil fuel type i consumed by power plants included in off-grid power plant class m in year y (mass or volume unit).

$NCV_{i,y}$ = net calorific value (energy content) of fossil fuel type i in year y (GJ/mass or volume unit).

$\eta_{m,y}$ = default net energy conversion efficiency of off-grid power plant class m in year y (ratio).

m = off-grid power plant class considered as one power unit.

y = the relevant year as per the data vintage chosen year.

i = fossil fuel types used.

• Option 3. $EG_{m,y}$ is estimated based on the capacity of off-grid electricity generation in that class and a default plant load factor, as follows:

$$EG_{m,y} = CAP_m \times PLF_{default,off-grid,y} \times 8760$$

Where,

$EG_{m,y}$ = net quantity of electricity generated and delivered to the grid by power unit m in year y (MWh).

CAP_m = total capacity of off-grid power plants in included in off-grid power plant class m (MW).

$PLF_{default,off-grid,y}$ = default plant load factor for off-grid generation in year y (ratio).

m = off-grid power plant class considered as one power unit.

y = the relevant year as per the data vintage chosen year.

The default plant load factor for off-grid generation ($PLF_{default,off-grid,y}$) can be determined using one of the following two options:

• Use a conservative default value of 300 hours per year, assuming that the off-grid power plants would at least operate for one hour per day at six days at full capacity (i.e. $PLF_{default,off-grid,y}$=300/8760); or

• Calculate the default plant load factor based on the average grid availability and a default factor of 0.5, assuming that off-grid power plants are operated at full load during approximately half of the time that the grid is not available, as follows:

$$PLF_{default,off-grid,y} = (1 - \frac{T_{grid,y}}{8760}) \times 0.5$$

Where,

$PLF_{default,off-grid,y}$= default plant load factor for off-grid generation in year y (ratio).

$T_{grid,y}$= average time the grid was available to final electricity consumers in year y (hours).

3.2 Carbon Emissions and Emissions Intensity in Thermal Power Industry

Thermal power industry is a major source of emissions of carbon dioxide, and the thermal power industry has accounted for about 50% of energy-related emissions. Total emissions and the corresponding average emissions intensity of the thermal power can be calculated from Energy Balance Table. So the power (thermal power) industry CO_2 emissions and emissions intensity based on using the latest available Energy Balance Table in year 2000-2011, which is shown in figure 1.

The figure suggests the thermal power industry's emissions continue to rise due to continued growth in generating capacity. But due to the presence of electricity shortage in 2003, the emission intensity of a large number of small units see a rebound in the first priority case followed by the downward trend after 2005 and 2009, which are still expected that this downward trend may stay for a while.

The trend of greenhouse gas production in China will has a better reaction for carbon emissions with stochastic volatility and accurately fits the predication of carbon emissions from thermal power enterprises. In the future years, carbon emissions grow under current Chinese development laws and trends in carbon emission will continue the current potential. Maintaining technical progress to improve energy efficiency and reduce energy consumption is essential to fully realize a low-carbon economy and thermal power enterprise in China.

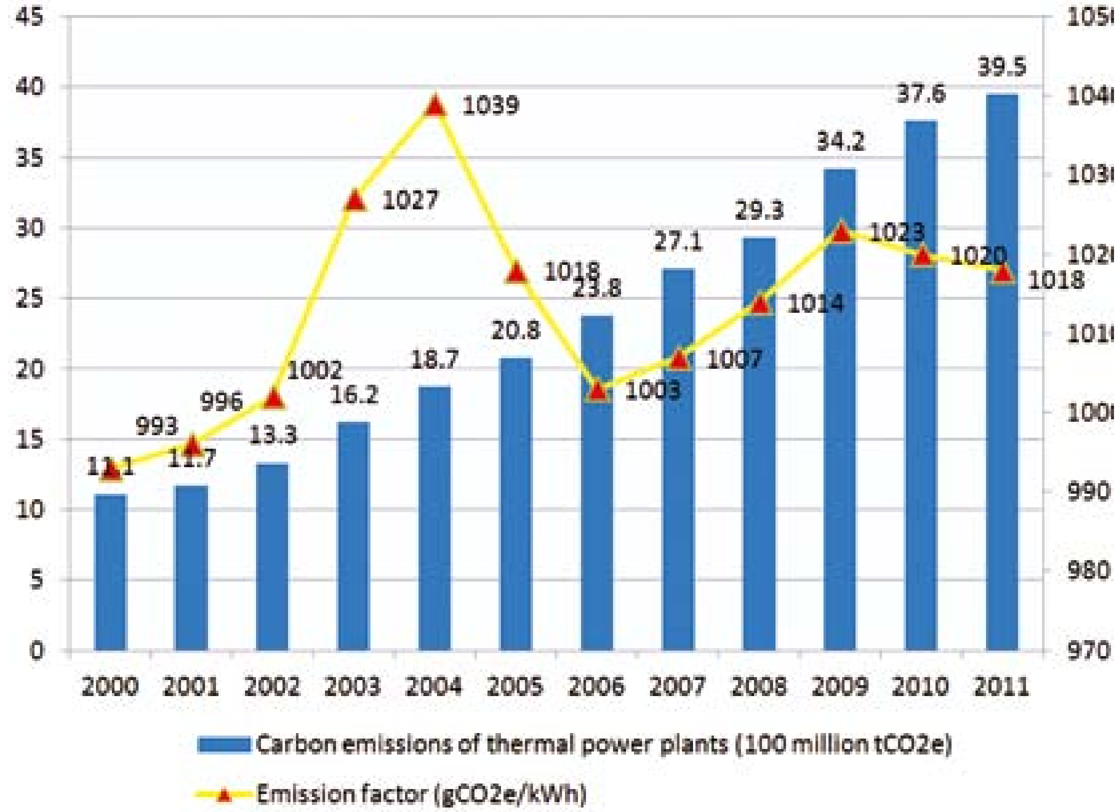

Figure 1
Total Emissions and Emissions Intensity of Thermal Power Industry

Data sources: from Chinese Electric Yearbook 2000 to 2012, Chinese Yearbook 2000 to 2012, and related carbon emission statistics.

CONCLUSION

This article analyzes the identification of greenhouse-gas emissions source in power industry in the first. The emissions of greenhouse gases in power industry (CO_2, CH_4, and N_2O) mainly present in the thermal power generation, heating and production process of biomass power generation enterprises. Moreover, the analysis of the electric power industry emission characteristics, strength and calculation methods emissions are illustrated, especially focusing on the analysis and calculations of the emission intensity of the thermal power industry carbon emissions, such as that of the typical coal power units, the subcritical, the supercritical and the ultra-supercritical as well as those features of fluidized bed boiler technologies like CFBC/PFBC, IGCC, and CCS. Different factors have been analyzed in the different environments and then drawn the conclusion that the greenhouse gas emission reduction in Chinese thermal power plants necessary and available.

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