The extension of continuous carbon emission monitoring system in China’s thermal power plants under the carbon market

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Abstract. China is facing severe climate pollution, thus the CO₂ emissions of thermal power plants which consume a lot of fossil energy, need to be strictly monitored. At the same time, the thermal power plants and the government will face brand new environment, where the exactly appropriate monitoring approach of CO₂ emission remains ambiguous. This study aims to distinguish monitoring approaches between Continuous Emission Monitoring System (CEMS) and factor-based approach on the basis of the operation features of China’s thermal power plants, analyzing the extension of CEMS. We review the major reducing greenhouse gas initiative in China—carbon market, and different emission monitoring approaches at first. We present the prospects of extension in CEMS’s technical features by analyzing an example of two generations using coal and gas, respectively, finding that CEMS is more accurate and dynamic. This study also presents the challenges by analyzing the refinement of factor-based monitoring approach. However, In contrast to many previous studies, we consider different influence in prospect and challenge from the market itself, the application experience and equipment installation basis. We finally draw an important conclusion that the factor-based monitoring approach is more suitable for China’s thermal power plants currently, but CEMS is more promising.

1. Introduction

China’s coal power is dominant in both installed capacity and power generation structure because of the abundant coal resources. It consumes more than 50% of the country’s coal and contributes more than 20% of its carbon dioxide emissions, which makes it necessary to promote the carbon market in China’s thermal power industry [1]. Pollutant monitoring of emission sources is the top priority in the carbon market. Factor-based method is the most widely used monitoring method at present, while Continuous Emission Monitoring System (CEMS) is the most advanced and intelligent monitoring method at present, and its performance in the carbon market of China’s power industry gains much attention recently.

[2] Considers that in the upcoming CM in China, participants will get the emission allowances for free, and they must optimize their generation and trading of emission allowance under a cap-and-trade scheme, which is an effective mechanism to achieve energy saving and emission reduction by setting the total carbon emission quota and trading emission allowance. [3] Denotes theoretically that CM is
an administrative approach derived from the Coase’s theory, used to control pollution by providing economic incentives. [4] Analyzes China’s pilots Emission Trading Scheme (ETS) respectively by comparing to well-established European Union ETS, points out that the duration of the current pilot ETS programs at the local level should be extended step by step before a mandatory nationwide ETS is formally initiated. For more details of the China CM, we recommend [5].

As for emission monitoring, which is one of the most important links in the process of the market operation, scholars pay more attention to its technical characteristics and functions. Australian Government Department of the Environment and Energy launched [6] in 2007, which requires the use of factor-based approach or Mass-Balance approach, but giving the detailed regulation about CEMS at the same time without mandatory requirement. As for European ETS, the government gives the detailed requirements of certain industries in [7], which indicates that for the mentioned emission sources (including some thermal plants, cement plants, etc.), the operators must use CEMS unless they can prove its cost is higher than the factor-based approach under the same monitoring effect. [8] mentioned that American Regional Greenhouse Gas Initiative (RGGI) requires all sources (equipment levels) that emit more than 25,000 t of CO₂ equivalent per year to be fully installed with continuous emission monitoring system (CEMS) from 2011 and report online to the Environment Protection Agency (EPA). Few literatures have expressed opinions based on the characteristics of the power industry and the construction foundation and policy environment of China's carbon market. [9][10] Present the most advanced and automated applied accounting measurement-based approach currently, which is based on CEMS. [11] Figures out that the emissions data reported to the China EPA provided a continuous record that can be used to guide further regulations and determine the compliance of stationary sources with their emission limitations. [12] Presents that the thermal plants have already equipped with basic devices needed for CO₂ continuous emission monitoring.

In this paper, we analyze the possibility of CEMS promotion in China's thermal power industry from the perspectives of application prospect and challenges. The analysis of the full text compares the existing monitoring approaches in the world and focuses on determining the reasonableness of different monitoring approaches in combination with the construction basis of China's carbon market, policy environment and the actual situation of thermal power industry. Specifically, 1) we have summarized the content and development of China's carbon market in detail, and studied the status of monitoring methods in the carbon market, 2) we carefully studied the parameter requirements, calculation steps and internal structure of the three most widely used monitoring methods, 3) we analyze the application prospect from the aspects of technical features, early efforts and available experience, 4) we enlighten the difficulty of application from the perspective of impact of other methods and market willingness.

2. Background
CEMS is a focused approach of this study to calculate the emissions of CO₂, existing as a key link and an important part of the carbon market. Furthermore, to highlight this study more precisely, we have to overview the China’s CM and the existing monitoring approaches.

2.1. Major initiative - carbon market
China has a long history of national policy in energy use. Premier Wen Jiabao was committed to reduce CO₂ emission intensity by 40-50% by 2020 compared to 2005 at the 2009 Copenhagen (Sweden) climate talk. Since then, the government has been keeping on digging the best possible ways to control industrial pollutant gas emission. In 2011, the National Development and Reform Commission (NDRC) officially approved carbon trading pilots in seven provinces and cities in China. Further, in 2013, NDRC confirmed the pilot projects of carbon trading in seven provinces and cities including Beijing, Tianjin, Shanghai, Chongqing, Guangdong, Hubei and Shenzhen [13],[14]. At the end of 2017, China announced the full launch of the national Carbon ETS, and took the power industry as a breakthrough to take the lead in enacting the Carbon Emission Trading Market Construction Plan (Power Generation Industry) which provides the definition of the basic CM trading
elements considering actual situation of China. CM is served as an alternative to administrative measures to achieve energy conservation and emission reduction, by setting trading rules including transaction participants, trading products, carbon financial derivatives, carbon quota total structure, initial quota allocation mechanism, and voluntary emission reduction offset mechanism.

**Figure 1. Structure of China’s carbon market.**

The CM of China's coal and power industry generally presents the pyramid structure as shown in the Figure 1. Based on trading participants, the initial quota to participate in the carbon market is obtained through initial quota allocation mechanism, and the remaining quota is traded through the spot market as a commodity. A mature carbon market develops financial derivatives on the basis of basic trading products that improve market efficiency and market functions. Through the Figure 1, it is not difficult to find that the different carbon emission monitoring approaches will directly affect the remaining carbon emission quota of the market subject, further affect the settlement of the secondary market, efficiency of the carbon market and the actual effect of emission reduction. Therefore, appropriate monitoring approach is the key point for the carbon market of China's coal power industry.

2.2. Monitoring approaches: composition and functions

In addition to the traditional Emission-Factor Approach (tEFA) used in China's coal power industry, there are also specific Emission-Factor Approach (sEFA) and CEMS widely used in the world. As for Mass-Balance Approach, it is a new method proposed in recent years which essence is still an indirect monitoring approach for a period of time. Considering that Mass-Balance Approach is not widely used and has little reference value for China's carbon market, the approaches discussed here does not include the Mass-Balance Approach.

Factors in the traditional approach only use the type of raw material as a reference factor, while the specific factors take fuel class, control technology, quality of operating conditions maintained, etc. into account. The sEFA is simply an upgrade of tEFA, and the rationale for estimating emissions by using factors has not changed. Both the US EPA’s *Mandatory Greenhouse Gas Emission Reporting Regulation 2009* and the EU’s *MRR-commission Regulation (EU) no601/2012* have expanded and upgraded the factor approach.

China's thermal power industry currently adopts a tEFA, and implements accounting and reporting in accordance with the specific requirements of the *China Power Generation Enterprise Greenhouse Gas Emission Accounting Approach and Reporting Guide (Trial)* issued on October 15, 2013. Companies are obliged to select the appropriate emissions factors according to their estimates, the final result of the carbon emissions from the three parts to obtain the sum [15].

- $E_1$ Carbon dioxide emissions from fossil fuel combustion production;
- $E_2$ Carbon dioxide emissions from the desulfurization process;
- $E_3$ Carbon dioxide emissions from electricity production purchased by enterprises.
The total greenhouse gas emissions of power generation enterprises are calculated as follows:

\[ E = E_i + E_2 + E_e \]

\[ E_i = \sum_j (AD_j \times EF_j); \quad AD_i = FC_i \times NCV_i \times 10^{-6} \]

\[ E_2 = \sum_i (CAL_i \times EF_i); \quad CAL_j = B_j \times I_j \]

\[ E_e = AD_e \times EF_e \]

- \( i \) Index of coal type from 1 to \( i \);
- \( j \) Index of desulfurizer type from 1 to \( j \);
- \( AD_i \) Activity level data of coal \( i \) in combustion process
- \( FC_i \) Fuel consumption of coal \( i \) in combustion process
- \( NCV_i \) Average low calorific value of coal \( i \) in combustion process
- \( EF_i \) Emission factor of coal \( i \) in combustion process
- \( CAL_j \) Activity level data of desulfurizer \( j \) in desulfurization process
- \( B_j \) Consumption of desulfurizer \( j \) in desulfurization process
- \( I_j \) The content of carbonate in desulfurizer \( j \) in desulfurization process
- \( EF_j \) Emission factor of desulfurizer \( j \) in desulfurization process
- \( AD_e \) The net amount of electricity purchased by the power generation enterprise
- \( EF_e \) The average annual emission factor of the power grid in the corresponding region

Table 1. Basic composition and functions of CEMS.

| Subsystems                           | Parameters                                      | Functions                              |
|--------------------------------------|------------------------------------------------|----------------------------------------|
| Particular matter monitoring system  | Concentration of particulate matter and gaseous pollutant | Calculating pollutant concentration    |
| Data acquisition system              | Flue gas temperature and flow rate              | Working out emission in flue gas       |
| Flue gas emission parameter system   | Flue gas moisture content                       | Displaying and printing various parameters and charts |
| Gaseous pollutant monitoring system   | Flue gas flow rate                              | Transmitting data to fixed pollution source monitoring system |
| Transmission and processing system   | Smoke oxygen                                    |                                        |

The actual measurement approach is mainly carried out by the CEMS. The basic composition and functions of it can be seen in Table 1. The CEMS consists of a particulate matter monitoring subsystem, a gaseous pollutant monitoring subsystem, a flue gas emission parameter measurement subsystem, a data acquisition, transmission and processing subsystem [12]. Through sampling and non-sampling approaches, the concentration of particulate matter and gaseous pollutants are measured, it can also measure many parameters such as the flue gas temperature, flue gas pressure, flue gas flow rate or flow rate, flue gas moisture content, smoke oxygen, etc. The CEMS is equipped with many other modern functions: calculating pollutant concentration and emissions in flue gas; displaying and printing various parameters and charts; transmitting data to fixed pollution source monitoring systems through data and graphic transmission systems.
3. Prospects

Since the monitoring approaches widely used in the world currently are mainly Emission-Factor Approach (including tEFA and sEFA) and CEMS, and China happens to use the former one (tEFA) now, when it comes to the prospects of CEMS’s extension in China’s coal power industry, we organize the following analysis mainly by comparing CEMS with tEFA.

3.1. Technical features - accurate monitoring

In order to illustrate the prospects in technical features more clearly, we choose a 1000 MW coal-fired generator and a 230MW gas-fired generator, both installed with CEMS, as the research object to find some features, using the hourly data collected in June, 2018. Then, we compare CEMS and tEFA in detail to analyze the challenges and the prospects behind these features.

In Figure 2, we compare two monitoring approaches for the same generation. It is not difficult to find from the following figure that no matter how the red curve (Generated Power) changes, the green curve (Monitoring Value of CEMS) is always higher than the black curve (Monitoring Value of tEFA).

![Figure 2. Comparison of monitoring approaches in emission and generated power.](image)

We can conclude that the calculated emission value using CEMS is always greater than the monitoring emission value using the tEFA, which means, in other words, CEMS ‘s accuracy is better.

As for the reasons, on the one hand, CEMS has a higher degree of automation as the content of the composition and functions of the CEMS system in the background section introduced, which can avoid many unnecessary system errors and calculation errors, and minimize the influence of human factors. However, China's thermal power industry still uses tEFA at present, and the initiation of carbon market increases the cost for power generation enterprises to participate in the power market competition, power generation enterprises tend to choose smaller factors to reduce their reported carbon emissions.

When it comes to the prospect, this feature can solve the problem that the power generation enterprises choose emission factors and related parameters in different ways, which affect the credibility of the enterprise's carbon emission calculation results. Precisely, CM achieves the optimal allocation of market resources by internalizing market externalities. The accuracy of CEMS can better find the true cost of the unit and reflect the energy-saving characteristics of the unit. This means that CEMS can generate more effective interaction with the power market through more accurate data, which will eventually be reflected in the transaction price of the trading center and the economic dispatch of units, achieving the goal of reducing carbon emissions.
3.2. Technical features - dynamic monitoring

In Figure 3, we compare the carbon intensity of the two monitoring approaches for the same generation. The carbon emission intensity, that is, the amount of carbon dioxide emitted per generator of power generation, can reflect the emission characteristics of the generator under different operating conditions. The CEMS is more sensitive to the start-stop process of the unit. When the unit output fluctuates, the measured method is more capable of following the change in power generation, and it can also more accurately reflect the carbon dioxide emissions under actual conditions. We can conclude that the dynamic monitoring performance of the CEMS is better than that of the tEFA, which means CEMS can better reflect the carbon emission characteristics when the output of the generator changes.

![Figure 3. Comparison of monitoring approaches in emission intensity.](image)

It is derived from the study that, the CEMS approach is based on the field-based measured data of the source, where data will be aggregated to obtain the relevant carbon emissions in certain reporting requirements in a very short time. In contrast, the data of tEFA are derived from the average value within a time period, so the variation of unit output in the same time period cannot be well reflected.

When it comes to the prospect, in the auxiliary service market which is a part of the power market, the thermal power unit using the CEMS will be able to more accurately verify the cost of peak shaving and frequency modulation. Specifically, as new energy generation increases, demand and pricing for ancillary services increases as it becomes increasingly difficult for power systems to absorb new energy. Due to the frequent participation of thermal power units in power grid peaking and frequency regulation, the output of thermal power units fluctuates significantly. Accurately reflecting the dynamic carbon emission in the process of providing services is helpful to find out the true cost in the process of providing services. For the power generation companies, CEMS can reasonably arrange their own bidding strategies, and for the market, CEMS can complete the most economical scheduling while considering the cost of emission reduction.

3.3. Foundation and experience

In this part, we draw the institutional foundation and technical foundation of CEMS’s extension by analyzing China's internalization of market externalities. By analyzing the types and trends of carbon emission monitoring approaches in America, the international experience of the promotion of CEMS is obtained.

During the implementation of full coverage of desulphurization, denititation and dust removal facilities in thermal power plants, China has installed online CEMS of dust, sulfide, nitride and other
pollutants in thermal power industry, providing valuable management experience for carbon emission monitoring in thermal power industry [12]. China's environmental monitoring stations at various levels are carrying out pollution source monitoring. The power plant enables the monitoring of industrial CO₂ emissions by simply increasing the CO₂ monitoring unit in the original device because monitoring factors have already included particulate matter, SO₂, NOₓ, etc. For industrial sources that have installed a continuous online monitoring system for flue gas, it just has to add a CO₂ analyzer to the analysis system unit in the monitoring station to realize continuous emission monitoring without changing the original sampling system and data transmission equipment.

In 2009, the RGGI became the first mandatory cap-and-trade program to limit U.S. carbon dioxide emissions. The study started early and the compilation system formed is relatively mature and stable. EPA has developed strict data quality control measures and issued relevant regulations and guidelines on data quality control, such as Mandatory Regulations on Greenhouse Gas Emission Reporting 2009, which requires all sources (equipment levels) that emit more than 25,000 t of CO₂ equivalent per year to be fully installed with continuous smoke monitoring systems (CEMS) from 2011 and to report online to the EPA.

4. Challenges

China's coal power sector is in the early stages of CM and electric power market with many operational and regulatory mechanisms still incomplete. The cost of carbon emission of power generation enterprises cannot be well transmitted to users through the power market, and the function of the carbon market in optimizing resource allocation has not been fully played, which leads to the small profit margin of clean units and the lack of incentive to change monitoring approach.

Meanwhile, tEFA is keeping on upgrading, with the problem of imprecision being greatly improved, forming a better version called specific Emission-Factor Approach. In the rest of this section, we analyze the challenges from the refined factor and the market participants.

4.1. Refinement of factor

The Emission-Factor Approach is still the longest, most extensive, and most experienced accounting approach in the world. Research on the CM in the United States, the European Union examines that CM designers in all regions have recognized the inaccuracy of the data in the Emission-Factor Approach and proposed effective improvement measures: Specific Emission-Factor Approach (sEFA).

US and EU based on the requirements of 2006 IPCC Guidelines for National Greenhouse Gas Inventories [16], all make provisions for delineating factors at different levels. They have different requirements for different emission bodies in accordance with following accounting principles:

1) Select the emission factor closest to the real situation;
2) Select the emission factor that is the easiest to obtain accurate activity data;
3) Select the emission factor recognized by the target user.

According to the above three principles, the United States divides factors into three levels while the European Union divides factors into four levels. Typically, larger the scale of the installation equipment, the higher the corresponding accuracy level. When the top-level approach is technically infeasible or causes unreasonable costs, the operator may use the lower layer. In the case of the United States carbon market, the regulations are as follow:

1) The first level uses the default emission factor, which is mainly for greenhouse gases released by fixed fuel combustion. In this level, greenhouse gas emissions from solid fuel combustion are addressed.

2) The second level is replaced by the country-specific emission factor, and the emission factor is calculated based on national data which take the state of technological development and different fuel characteristics (carbon content, etc.) into account and will change over time. A comparison between the emission factors of the United States and the default emission factors of solid fuel combustion in
the energy industry provided by IPCC (2006) can avoid various errors. The second approach is more accurate than the first one.

3) The third level takes the different possibilities of fuel combustion and the combustion approaches into account in order to derive emission factors for specific control technologies. The third approach is more accurate than the second one.

Although the sEFA is still an indirect estimation method, it reflects the emission characteristics of different emission sources by dividing levels, which greatly improves the accuracy. In addition, since the sEFA is an improvement on the tEFA, there is no need for major changes in the accounting and regulatory system. What’s more, the generation enterprises are more familiar with it and the upgrade of monitoring methods can be achieved at a minimal cost. Therefore, sEFA is a big challenge for the CEMS’s extension at this stage in China’s coal power industry.

4.2. Willingness of market participants

China is the country with the largest proportion of coal power generation due to its advantages in coal resources. The United States is the most similar one of China's power generation among the developed countries. It mandates that all emissions sources (equipment levels) emitting more than 25,000 tons of carbon dioxide equivalent per year must be installed with CEMS of flue gas in 2011, and submit the monitoring data to the US EPA online meeting the requirements designed to ensure that these monitors are properly installed, operated and maintained particularly [17].

As for China, through the collection and comparison of the carbon emission data of thermal power units in the thermal power plants, it is found that the accounting results under the measurement-based approach are always larger than the accounting results under the tEFA. In the case that the carbon emission quota is unchanged, and CEMS is not fully popularized, the power generation cost of the unit using the actual measurement-based approach is significantly higher than that of the unit using the factor-based approach of the same type. The units that adopt the CEMS will be in an unfavorable position when participating in the power market quotation and are likely to face the result of less power outage.

In addition, due to the extra investment cost and the following management issue, CEMS will inevitably be in conflict with the coal power industry.

5. Conclusions

The carbon emission trading market is an effective way for China's coal-fired power plants to achieve emission reduction targets, and carbon emissions monitoring are a key link in the transaction process. In China's thermal power plants, the tEFA is generally adopted. The factor is determined by the emission generator itself or the default factor provided by the state. Due to the lack of unified management, the factor setting is rough, resulting in a reduction in data validity.

This study deeply analyzed the prospects and challenges of CEMS by comparing with factor-based monitoring approaches in technique and economics, etc., which shows that CEMS has better performance in monitoring more dynamically and accurately, as well as the advantages in foundation and experiences over the factor-based approaches. Furthermore, the automatically operating system, working as the foundation of aforementioned technical advantages, can offer mass data of thermal power plants to CM’s verification institutions and technology companies, increasing operating efficiency of CM and creating lucrative market in energy management service respectively. When these benefits scale up at country level, the appliance of CEMS will definitely decrease the time and labor cost running a countrywide CM, and vitalize the fields in equipment producing and technology service.

However, every coin has two sides. Despite of the high installment and maintenance cost, rigid supervision and increment of CO₂ emission value, the thermal plants will pay more on emission tariff and technology upgrades. The extension of CEMS will face more challenges of CM participant (i.e. thermal power plants for now).
As to sEFA, an upgrades of tEFA based on rough and ready multiplier, shows more details of producing in fuel consuming, devices life, etc. Though lack in the dynamic property, it can also increase the accuracy of monitoring and save installment cost, which will be easily accepted by thermal power plants in CM currently.

To Summarize, we cannot rule out the possibility that the Chinese government may think China's thermal power plants, the first pilot industry to enter the Chinese CM, is obliged to reflect the advanced nature and leading role by forcing whole industry using CEMS at the current stage. Considering that the promotion of sEFA can also increase the accuracy of emission data to a certain extent and costs less compared to the CEMS, the authors believe that sEFA is more suitable for China's coal power industry currently in the transition to a national CM. However, the CEMS will gradually become the first choice of emission monitoring as the development of Chinese CM and equipment manufacturing technology will gradually decline of installation and operation cost.

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