Carbon Footprint Accounting for Gas Power Plant Carbon Capture and Storage System

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Abstract. Carbon capture, utilization, and storage (CCUS) is an important technology for reducing carbon emissions in the thermal power industry. However, there is currently no accounting method for the full lifecycle carbon emissions of CCUS projects. This article presents the full lifecycle carbon footprint accounting of a CCS system in a gas power plant, with reference to the carbon footprint accounting method of the power generation industry. The full life cycle carbon footprint accounting process of the CCS system in gas power plants mainly includes the determination of carbon emission boundaries, investigation of emission sources, accounting of carbon emissions, and verification of accounting results.

Keywords: Accounting Method, life cycle, carbon footprint.

1 Introduction

CCUS is promoted by the International Energy Agency (IEA) and the Intergovernmental Panel on Climate Change (IPCC) as one of the most necessary technology to achieve carbon peaking and carbon neutrality goals. According to the Third National Assessment Report on Climate Change, China's CCUS technology is expected to achieve an annual CO_2 reduction of hundreds of millions of tons by 2030. At present, the large-scale application of CCUS technology is still constrained by factors such as cost, energy consumption, safety, and reliability. The assessment of the carbon reduction capability of CCUS technology also determines whether it can become a key technology for carbon neutrality.

At present, there are only some basic Standard and methodology in the field of CCUS greenhouse gas emissions accounting. Volume 2, Energy, of 2006 IPCC Guidelines for National Greenhouse Gas Inventory, refers to methods of accounting for carbon emissions in CCUS implementation[1]. The " Carbon dioxide capture, transportation and geological storage - Quantification and verification (First Edition)" (ISO/TR 27915:2017) summarizes several international methodologies for CCUS accounting, and discusses their differences and applicable conditions[2]. Jinfeng Ma et

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al. discussed the verification and quantification methods of underground CO_2 storage for the CCUS project carried out by Shengli Oilfield, and gave the accounting steps[3].

China has established technical standards for the preparation of greenhouse gas emission reports and implemented them in multiple fields. However, due to significant industry and regional differences in Carbon emission factors, many fields lack quantitative technical methods, which makes it impossible to carry out accounting work. Among the currently issued guidelines for greenhouse gas emissions accounting and reporting in 24 key industries in China, only the chemical and petrochemical industries mention the need to deduct CO_2 supplied to other enterprises during accounting. In addition, there is no description of quantitative methods for greenhouse gas emissions during CO_2 capture, transportation, and storage processes, and there is still a lack of quantitative methods for greenhouse gas emissions reduction using CCUS technology.

This paper is based on the Measures for the Administration of Carbon Emission Permit Trading, Accounting methods and Reporting guidelines for greenhouse gas emissions of enterprises - Power generation facility (Revised 2022 Edition), Guidelines for the preparation of Provincial Greenhouse Gas Inventories, and 2006 IPCC Guidelines for National Greenhouse Gas Inventory. The carbon footprint calculation method of CCUS project of thermal power plant is studied, and the relevant calculation is carried out based on the CCS system of a gas power plant.

2 Carbon Footprint Accounting Method

2.1 Accounting Method

The main methods for calculating carbon footprint include life cycle method, input-output method, and measurement method[4]. The input-output method calculates carbon footprint by compiling input-output tables and utilizing input-output values. This method is applicable at the macro level, such as government and enterprises; The life cycle method calculates the total carbon emissions through all input and output data throughout the entire life cycle of an activity. This method is applicable at the micro level, such as products and services. The actual measurement method is based on the measured basic data of emission sources and summarizes the relevant carbon emissions. It is divided into two methods: on-site measurement and off-site measurement. On site measurement is generally carried out by installing a carbon emission monitoring module in the Continuous Emission Monitoring System (CEMS), which directly measures its emissions through continuous monitoring of concentration and flow rate; Off-site measurements are conducted by collecting samples and sending them to relevant monitoring departments for quantitative analysis using specialized testing equipment and techniques.

According to the applicable scope of various calculation methods for carbon footprint, the life cycle method is suitable for analyzing and calculating the carbon footprint of the CCS system. This article uses the life cycle method to analyze the main carbon sources of the CCS system life cycle and calculate the total carbon emissions.

2.2 The calculation process and criteria of the lifecycle method

The application of the lifecycle method to calculate the carbon footprint of a product or service mainly involves four steps[5-8]:

(1) Determine the various stages and emission sources of the product or service lifecycle;

(2) Query and determine carbon footprint factors;

(3) Collect product or service data and calculate carbon footprint;

(4) Analyze the results of carbon footprint calculation.

2.3 Lifecycle carbon emission accounting of CCUS project

CCUS consists of CO_2 capture, transport, use, such as injection, seal stage[9]. There are fixed emission methods and factors in the CO_2 capture and transportation process, and the emission factor method can be used. However, since emissions and leakage from CO_2 injection and storage systems are irregular and the process lacks emission factors, direct measurement or mass balance methods are often used. The project needs to have sound monitoring and detection equipment and systems to ensure reliable and authentic monitoring data, including temperature, pressure, CO_2 concentration, flow rate, etc.

The entire lifecycle of the CCS system mainly includes construction, operation, and decommissioning. The full lifecycle carbon emissions mainly include direct carbon emissions generated by system operation, indirect carbon emissions generated by system operation during construction and operation periods, and emission sources related to upstream or downstream industries during project operation. The carbon emissions of each stage of the project's entire lifecycle are the sum of the usage of all emission sources and their emission factors in this stage[10-12].

$$CF_i=\sum (AD_{ij} \times EF_{ij})$$

In the equation:

AD_{ij} is the quantity of the j-th emission source in the i-th stage, expressed in kg, m^3, or kWh;

EF_{ij} is the carbon footprint factor of the j-th emission source in the i-th stage;

CF_i is the total carbon emissions of the i-stage product or service.

The direct carbon emissions of the CCS system mainly include the carbon emissions of the system itself and the carbon emissions directly generated by system operation. The indirect carbon emissions of CCS systems generally refer to the carbon emissions generated indirectly due to energy consumption during system operation, such as the raw materials and energy consumed by capturing CO_2 in flue gas using chemical absorption method. The carbon emissions during the construction and operation stages of the CCS system include carbon emissions from building materials mining and transportation, equipment manufacturing and installation, and equipment operation and use.

3 Carbon Footprint Accounting Method

The annual power generation utilization hours of a gas-fired power plant are 4500 hours. At the beginning of construction, a CO_2 capture system was built at the tail of the waste heat boiler. The designed capture capacity is 5t/d, and the flue gas treated at 100% load is 3242Nm^3/h. The CO_2 capture system and the gas unit are put into operation at the same time. Its operation data are shown in Table 1:

Table 1. Main operating parameters and performance indexes of CO_2 capture system

Project	**Parameters**
Flow rate of flue gas	3093±102Nm^3/h
Flue gas at the entrance of washing tower	CO_2:(4.55±0.05)%(vol%);77.0°C~81.0°C; 5.0KPa~5.5 KPa(g)
Purification gas at the outlet of recovery tower	CO_2:0.46%(vol%); 45.0°C~48.0°C
The amount of CO_2 capture	(128.1±4.2)Nm^3/h; (0.25±0.01)t/h
The CO_2 capture efficiency	90.6±1.9%
MEA consumption	3.80 kg/kNm^3 CO_2
Low pressure steam consumption of reboiler	4.51 t/kNm^3 CO_2
The CO_2 capture power consumption (excluding compressed and liquefied)	192kwh/kNm^3 CO_2

The average CO_2 capture rate of the system is 90.6%, the MEA consumption is 3.80kg/kNm^3 CO_2, the low pressure steam consumption of the reboiler is 4.51t/kNm^3 CO_2, and the CO_2 capture power consumption (excluding compression and liquefaction) is 192kwh/kNm^3 CO_2.

Firstly, calculate annual emissions reductions in carbon capture systems for gas-fired power plants according to the flow rate of flue gas, CO_2 component and capture rate of the CCS system.

The annual emission reduction of the CCS system = 3093 * 4.55% *4500 * 90.6%/ 22.4*44/1000 = 1127.03 tons.

3.1 Direct carbon emissions during CCS system operation

The carbon emissions of CCS system mainly include the carbon emissions of the system itself and the carbon emissions of the system electricity and heat. The carbon emission of the system itself generally refers to the CO_2 dissipation of the capture system, that is, the amount of CO_2 that is not captured.

(1) CO_2 consumption of the capture system (CO_2 not captured) = 3093 *4.55%*4500*(1－90.6%)/22.4*44/1000=116.93 tons.

(2) Emissions generated by grid power collection (plant power consumption) during the input process of the capture system = 192 /1000*3093 *4.55% *4500*90.6%/1000*0.5703(2022 average grid carbon emission factor) = 62.83 tons.

(3) Emissions generated by steam consumption during the input process of the capture system = 4.51 *3093 *4.55%*4500*90.6%/1000(2752(enthalpy of reheat steam)－604(Enthalpy of hydrophobicity))/1000*0.056(Average carbon emission factor for heating steam in gas-fired power plants in 2022) = 311.27 tons.

In summary, the direct carbon emission of CCS system during operation is 491.03 ton.

3.2 Indirect carbon emissions during CCS system operation

For each year of operation of the system, the carbon emissions of absorbent consumption for the CCS system operation = 3.80 *3093 *4.55% *4500* 90.6%/ 1000* 26.5（Carbon emission factors of the MEA production process）*10^{-6} = 0.05 tons.

3.3 Carbon emissions during the construction phase of CCS system

Carbon emissions in the construction process of CCS system mainly include infrastructure construction emissions, equipment manufacturing and installation emissions and related building materials transportation emissions. The carbon emission of CCS system construction mainly comes from the energy consumption in the production process of building materials and the material consumption in the construction process. The capture equipment of CCS system mainly includes scrubber, absorption tower, regeneration tower, recovery tower, liquid heat exchanger, reboiler, flue gas separator, flue gas separator, etc. The equipment of the liquefaction compression part mainly includes compressors, ice makers, CO_2 heaters, CO_2 condensers, CO_2 storage tanks, etc. The main equipment is shown in Table 2. The carbon emission factor[13-14] of main materials in LCA evaluation are shown in Table 3.

Table 2. CCS system equipment table

Equipment	**Quantity**	**Individual weight (kg)**	**Total weight (kg)**
Capture system			
Wash water cooler	1	119	119
Lean liquid cooler	1	109	109
Lean and rich heat exchangers	1	217	217
Regas cooler	1	109	109
Reboiler	1	585	585
Regas separator	1	201	201
Underground tank	1	485	485
Alkaline tank	1	484	484
Strainer	1	205	205
Washing tower	1+1(The two are	3650	3650

Equipment	**Quantity**	**Individual weight (kg)**	**Total weight (kg)**
Recycling tower	installed together)		
Absorption tower	1	4985	4985
Regeneration tower	1	3000	3000
Washing pump	2	--	--
Recovery pump	2	--	--
Rich pump	2	--	--
Lean pump	2	--	--
Submerged pump	1	--	--
Alkaline pump	1	--	--
Compression system			
Ice machine	1	2360	2360
CO_2 condenser	1	425	425
CO_2 heater	1	430	430
CO_2 storage tank	1	3097	3097
$CaCl_2$ storage tank	1	406	406
CO_2 dewatering tank	2	246	492
Filling pump	1	--	--
$CaCl_2$ solution pump	1	--	--

Table 3. CO_2 emission factor of major materials

item	**steel**	**concrete**	**oil**	**pump**
CO_2 (g/kg)	1160	30	3216	123kg/stage

The CCS described here includes only the capture and liquefaction compression components, thus simplifying the relevant materials when accounting for system carbon emissions, the main materials used during the construction of CCS system are shown in Table 4.

Table 4. The main materials used during the construction of CCS system

Material (kg)	**steel**	**concrete**	**oil**	**pump**
Capture equipment	14149	0	0	10
Compression equipment	7210	0	200	2

Table 5. CO_2 emission during the construction of CCS system

Material (kg)	**steel**	**concrete**	**oil**	**pump**	**total**
Capture equipment	16412.84	0	0	1230	17642.84
Compression equipment	8363.60	0	643.20	246	9252.8

The carbon dioxide emissions from the main materials of carbon capture systems are shown in Table 5. In summary, the carbon emission of CCS system construction phase is 26.90 tons.

3.4 Carbon emissions during decommissioning and shutdown of CCS systems

According to existing studies[15], the carbon emissions in the decommissioning stage of the project are simplified by 10% of the carbon emissions in the construction stage, so the carbon emissions in the decommissioning stage of the project are 2.69 tons.

3.5 Life cycle carbon emission reduction of CCS system

According to the above results, the life cycle carbon footprint of the CCS system is shown in Figure 1.

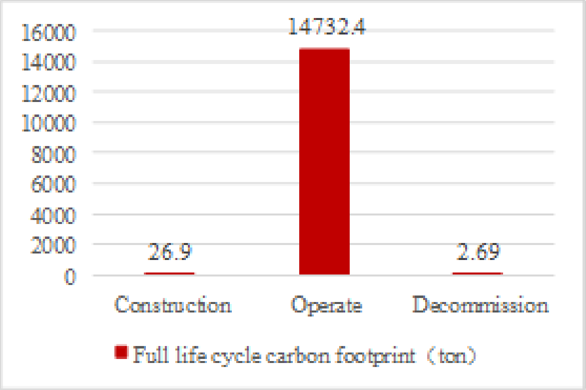

Fig. 1. Life-cycle carbon footprint of CCS systems in gas-fired power plants

The designed service life of the gas generating unit is 30 years, and the CCS system is built simultaneously when the gas generating unit is put into operation. Therefore, the life cycle carbon emission reduction of CCS system is 19048.91 tons.

Table 6. Life-cycle carbon footprint of CCS systems in gas-fired power plants

period	**construction**	**operate**	**decommission**	**The project emission reductions**	**Actual project emission reduction**
CO_2 (ton)	26.90	14732.4	2.69	33810.9	19048.91

Life-cycle carbon footprint of CCS systems in gas-fired power plants are shown in Table 6. According to the system carbon footprint map, the largest source of carbon emissions from CCS systems is the direct carbon emissions during system operation. Therefore, increasing the carbon capture rate of CCS system and reducing the energy and power consumption of CCS system can effectively reduce the carbon emissions of the whole life cycle of CCS system.

4 Conclusions

At present, China has entered a period with carbon reduction as the key strategic direction, strengthening the control of the total amount and intensity of energy consumption, and promoting the gradual shift from dual control of energy consumption to dual control of carbon emissions is the only way to achieve " carbon peaking and carbon neutrality goals". CCUS technology is an important technology for thermal and electric carbon emission reduction, and it is urgent to establish a special accounting method for full life cycle carbon emission. According to the current domestic and foreign carbon emission accounting policies, regulations and research progress, this paper carries out the life cycle carbon emission accounting for the existing gas power plant CCS system, and puts forward the following suggestions on the carbon emission accounting methods for similar projects:

- CCUS project accounting boundary CO_2 capture, transportation, utilization, injection, storage and other links. Direct emissions in the implementation of CCUS projects must be accounted. Its indirect carbon emissions and life-cycle carbon emissions are proposed to be included in the accounting scope.
- There are two ways to account for carbon emissions. The carbon emission factor method is applicable to the capture and transportation system with regular and more regular emission factors, while the direct measurement and mass balance method is applicable to the injection and storage system with more overflow and irregular discharge.
- The carbon emission accounting results of the project must be inspected and verified during carbon emission accounting.

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