

Life cycle assessment of coal-fired power plants and sensitivity analysis of CO₂ emissions from power generation side

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Abstract. The life cycle assessment and environmental impacts of a 1000MW coal-fired power plant were carried out in this paper. The results showed that the operation energy consumption and pollutant emission of the power plant are the highest in all sub-process, which accounts for 93.93% of the total energy consumption and 92.20% of the total emission. Compared to other pollutant emissions from the coal-fired power plant, CO₂ reached up to 99.28%. Therefore, the control of CO₂ emission from the coal-fired power plants was very important. Based on the BP neural network, the amount of CO₂ emission from the generation side of coal-fired power plants was calculated via carbon balance method. The results showed that unit capacity, coal quality and unit operation load had great influence on the CO₂ emission from coal-fired power plants in Guangdong Province. The use of high volatile and high heat value of coal also can reduce the CO₂ emissions. What's more, under higher operation load condition, the CO₂ emissions of 1 kWh electric energy was less.

1. Introduction

With the rapid development of economy in China, the amount of energy consumption has increased continuously by 120% in recent decade, resulting in the increasingly serious environmental problems. Guangdong Province is a big economic province in China. However, with the rapid economic development, it has been with high pollution, high emissions and high energy consumption. The CO₂ emissions during energy conversion process in the electric power industry of Guangdong Province accounted for 50% of the total emissions, thus the CO₂ emissions reduction of electric power industry should be attained great attention.

Since coal-fired power plant is one of the largest CO₂ emission source in China, calculating the CO₂ emission amount accurately and scientifically is necessary. Life Cycle Assessment (LCA) can comprehensively analyze the environmental impact of coal-fired power plants from construction to decommissioning, which can provide valuable advice for environmental management of coal-fired power plants. This work focused on the analysis of CO₂ emission amount during the operation process of the power plant and the sensitivity analysis of CO₂ emission. These findings can provide important information for reducing the CO₂ emission from the coal-fired power plant efficiently and



economically to achieve the goal of energy saving and emission reduction and ecological environment protection.

2. Life cycle assessment of coal-fired power plants

2.1. System boundary

The lifecycle system boundary of coal-fired power plant was shown in Fig.1. Especially, it focused on the CO₂ emissions from the operation process of power plant.

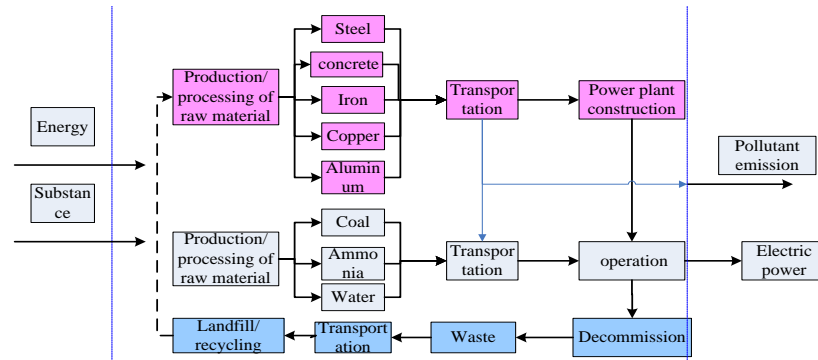


Figure 1. System boundary

2.2. Mining, smelting and transportation of raw material

The raw materials needed to construct a coal-fired power plant included steel, concrete, iron, copper and aluminum. The energy consumption required for mining, smelting and transporting of the raw materials and gaseous pollutants were listed in the Table 1.

Table 1. The energy consumption required for mining, smelting and transporting of raw materials and gaseous pollutants (kg/t)

Item	Standard coal	CO ₂	SO ₂	NO _x	CH ₄	CO	VOC	N ₂ O	COD	Dust
Steel	1523.62	2435.862	5.914794	5.242415	0.009022	0.80976	0.178762	0.004041	0.254	93.42482
Concrete	191.6065	689.364	0.813211	1.37852	0.896079	0.12581	—	—	0.242358	1.031
Fe	535.73	1535.862	4.034742	5.242415	0.009022164	0.809759883	0.178762	0.00404137	—	32.72135
Cu	120.1	18381.8	1298.1	54.1						
Al	77.8	822	2.09	2.98	9.16	0.761	—	—	—	2.39

2.3. Mining, processing and transportation of coal

(1) Resource consumption and pollutant emission

Mining phase required the consumption of coal, steel, wood, gasoline, diesel, and electricity. Previous study [1] provided the information of resources consumption for coal mining stage. In the processing stage, the coal jigging method was used in this study, according to the 2011th national average, washing 1 t of coal consumed 6.52 kWh of electric power [2] which converted into about 2.1842 kg of standard coal.

Pollution generation from the coal mining and processing included: air pollution, water pollution, solid waste pollution, coal-bed methane escape and so on.

(2) Coal transportation

In this paper, the railway transport distance was estimated to be 524 km based on the average transport distance of Datong-Qinhuangdao Railway [3]. Water transport distance was estimated to be 2452 km based on shipping distance from Qinhuangdao to Guangzhou [3]. In terms of highway, combining with the traffic volume based on the vehicle axle load characteristics, the average mileage of highway was estimated to be 171.31 km. The actual coal demand of 1000MW unit was 0.615kg/kWh. Therefore, Based on the above data and calculating methods [4-8], the energy consumption and pollutant emission during the mining, processing and transportation of coal for 1000MW unit were listed in Table 2.

2.4. Construction of coal-fired power plants

The construction stage of power plant mainly included the mining, processing, transportation of raw materials, plant construction and equipment installation. The transportation mode of the building materials was mainly highway, and the average transportation distance was 171.31 km. According to the amount of building materials demand for Pinghai Power Plant (1000MW), the energy consumption and pollutant emission during the consumables production, power plant construction and transportation were shown in Table 2.

2.5. Coal-fired power plant operation

For the gaseous pollutants emission during unit operation, the amount of emissions were the sum of the amount of direct emissions from the unit after tail gas treatment and the amount of indirect emissions from the production process of desulfurization and denitration catalyst. The amount of pollutant emissions during the operation process of a 1000MW power plant were listed in Table 2.

2.6. Power plant decommissioning

Due to the lack of plant removal and waste recycling data, the decommissioning phase only considered the impact of transportation of building material waste. The calculation method of total energy consumption, resource consumption and pollutant emission of the decommissioning phase are consistent with those of other stages. The building materials waste was transported by road. The average transportation distance was estimated to be 171.31 km. The energy consumption and pollutant emissions during the decommissioning phase of a 1000MW unit were shown in Table 2.

2.7. Solid waste treatment

During the operation process of power plant, the main solid waste were ash and gypsum[9]. The amount of ash residue was based on the amount of electricity supplied, the ash content of coal, and the amount of coal used. All the solid wastes were transported to the landfill[10]. In this study, only the energy consumption and pollutant emissions during the transport of solid waste were considered. The average transportation distance was estimated to be 171.31 km. The energy consumption and pollutant emissions of solid waste transportation were shown in Table 2.

2.8. Comprehensive analysis

According to the inventory analysis of each sub-process, the total life cycle inventory of the 1000MW coal-fired power plant was shown in Table 2.

Among the energy consumption of coal-fired power plants, coal accounts for 98.13%. And CO₂ emissions account for 99.28% among the pollutant emissions. It could be seen that operation phase has significant influence on the LCA of coal-fired power plant. Therefore, it was necessary to adjust the operation mode of coal-fired power plants to achieve the goal of energy saving and emission reduction.

Table 2. The total life cycle inventory of the 1000MW coal-fired power plant

Process	Energy consumption kg/kWh			Pollutant emissions g/kWh								
	Natural gas	Standard coal (kg/t)	Oil (kg/t)	CO ₂	CH ₄	NO _x	SO ₂	Dust	CO	VOC	N ₂ O	NH ₃
Consumables production and power plant construction	1.69423E-10	0.000522363	1.85981E-05	1.112215911	0.000486029	0.00255305	0.00640498	0.026218142	0.000331623	5.31633E-05	1.95696E-06	—
Transportation	—	—	7.10851E-06	0.021729433	6.09838E-07	0.000143847	6.89923E-06	2.95395E-06	7.00098E-05	1.31909E-05	7.8379E-07	—
Mining and processing	—	0.013092609	0.000460688	41.02807191	3.300998796	0.272579893	0.288525615	0.130144819	0.037791519	0.001637579	0.000399942	—
Transportation	—	0.001794761	0.002282835	12.07495082	0.000422582	0.230026413	0.137798994	0.01748268	0.03770875	0.007524703	0.000249818	—
operation	—	0.293406552	0.0022	726.868942	0.012006766	0.662047311	0.279376256	0.117552663	0.133452108	0	0.003168	1.38368E-08
decommissioning phase	—	—	7.10851E-06	2.17294E-02	6.1E-07	1.43847E-04	6.89923E-06	2.95395E-06	7.00098E-05	1.31909E-05	7.84E-07	—
Solid waste treatment	—	—	0.000921	2.814017328	7.89756E-05	0.018628607	0.000893468	0.000382545	0.009066452	0.001708256	0.000101503	—
Total	1.69423E-10	0.308816284	0.005896908	783.9416568	3.313993759	1.186122968	0.713006213	0.291786757	0.218420462	0.010950084	0.003922004	1.38368E-08

3. Sensitivity analysis of CO₂ emission from power generation side

From the LCA of coal-fired power plants, it could be seen that the CO₂ emission from coal-fired power plants accounted for the most proportion, especially from the generation side. Therefore, the sensitivity analysis of CO₂ emission was particularly important. The unit capacity, coal quality, unit efficiency, and operation load would affect the CO₂ emissions during the operation process.

3.1. CO₂ emissions calculation method

Theoretically, the amount of CO₂ produced by coal combustion is the product of the complete combustion reaction of C in the coal with the oxygen in the air. If the carbon content of the received coal is Car%, 1 g of received coal would produce 44/12 Car/100 (g) CO₂ under complete combustion condition.

Actually, coal burning in the furnace could not be completely burned, resulting in part of C remained in the fly ash and ash residue. Therefore, actual CO₂ emission amount should be deducted from the C in the fly ash and ash residue, and CO₂ emissions could be expressed as:

$$M_{\text{CO}_2} = \frac{44}{12} B(C_{\text{ar}} - \sum C) \quad (1)$$

Where M_{CO_2} was CO₂ emissions amount (t/h); B was the fuel consumption amount,(t/h); C_{ar} was the carbon content of the fuel as received basis(%); $\sum C$ for the total amount of unburned carbon, including fly ash and ash residue (%). Consequently, the CO₂ emissions from 1 kWh of electric power can be expressed as:

$$M_{\text{e,CO}_2} = \frac{44}{12} b_s \frac{29.703}{Q_{\text{ar,net}}} (C_{\text{ar}} - \frac{A_{\text{ar}} C_{\text{a}}}{100 - C_{\text{a}}}) / 100, \text{ g/kWh} \quad (2)$$

Where b_s was the coal consumption rate of power supply g/kWh; $Q_{\text{ar,net}}$ was the low heating value of coal, MJ/kg; A_{ar} was the ash content of received coal %; C_{a} was the average carbon content of the ash including fly ash and ash residue),%.

The average carbon content of the ashes was 0.93 according to the recommendations of the boiler design. only the coal moisture, ash, volatile, heat value and other parameters of coal were tested. Based on the relation between the proximate analysis and elemental analysis of coal, BP neural network prediction method was adopted to obtain the C content in the coal[11].

3.2. Effect of coal quality on CO₂ emission

In this section, a 350MW supercritical unit in Guangdong Province was selected as the research object. The operation data of the unit under the same operation load (70% THA) with different coal quality were selected to calculate the CO₂ emission and comparative analysis. The proximate analysis of coal was adjusted by the benchmark method. Table 3 showed the corresponding b_s , $Q_{\text{net,ar}}$, C_{ar} and $M_{\text{e,CO}_2}$.

Table 3. CO₂ emissions from units with different coal quality

Date	b_s /g/kwh	$Q_{\text{net, ar}}$ /MJ/kg	C_{ar} /%	A_{ar} /%	$M_{\text{e,CO}_2}$ /g/kwh
2015/1/25	311.09	22.00	57.44	12.33	888.82
2015/2/4	307.98	21.78	56.39	11.39	866.79
2015/3/27	312.79	22.12	59.39	10.82	913.08
2015/3/30	310.81	21.98	58.46	10.93	898.74

As shown in Table 3, as the coal with higher volatile content was used, the CO₂ emission was lower. The effect of ash and moisture content on CO₂ emissions was tiny. In general, the high ash content of coal would increase the mechanical incomplete combustion loss of the boiler, thus it needed more coal to supplement the heat loss. As a result, the CO₂ emission increased. When the ash content of coal is high and the heating value is low, the poor combustion property and extra energy consumption of the boiler would cause the increasing of CO₂ emissions.

3.3. Effect of operation load on CO₂ emission

The operation data from the same coal quality (Neimeng coal: Yitai coal = 1:2) under the different operation load (75% THA, 50% THA and 40% THA) The coal consumption rate at each operation load could be obtained from the coal consumption — operation load curve($y = -4.630E-07x^3 + 1.017E-03x^2 - 7.649E-01x + 4.701E+02$, $R^2 = 9.941E-01$) It can be seen from Table 4 that the higher operation load was, the less the CO₂ emitted.

Table 4. CO₂ emissions under different operation load factor

Load factor	bs/g/kwh	Qnet, ar/MJ/kg	Car/%	Aar/%	Me,CO ₂ /g/kwh
75%	275.26	21.95	58.31	23.48	793.38
50%	285.56				823.06
40%	297.50				857.48

4. Conclusion

(1) The energy consumption and pollutant emission of operation phase of power plant are the biggest. The energy consumption accounted for 93.93% of total energy consumption and pollutant emissions accounted for 92.20%. The largest proportion of pollutant was CO₂ which accounted for 99.28%. It was necessary to adjust the operation mode of coal-fired power plants to achieve the goal of energy saving and emission reduction.

(2) The unit capacity, coal quality and unit efficiency would affect the CO₂ emission during the operation of coal-fired power plants. The higher heating value of coal, the less CO₂ emission. The lower unit operation load, the higher CO₂ emission.

Acknowledgement

This work is supported by Guangdong Province Key Laboratory of Efficient and Clean Energy Utilization(2013A061401005), South China University of technology; Key Laboratory of Efficient and Clean Energy Utilization of Guangdong Higher Education Institutes (KLB10004), China Southern Power Grid Science and Technology Project K-GD2014-178 (GD2014-0130).

Reference

- [1] Mingjun W 2011 The Life Cycle Assessment of Coal-fired Power Generation. (Taiyuan: Taiyuan University of Technology)
- [2] Bureau G P 2011 Notice of improving feed-in tariff of Coal-fired Power Plants.
- [3] Liangliang Z 2011 Assessment on Whole Life Cycle of Clean Coal-fired Power Generation Technology.(Chongqing:Chongqing Univesity).
- [4] Dejian X 2010 The Research on Life Cycle Carbon Emissions Measurement of Electric Power Generation Side Based on the Scenario Analysis Method.(Chongqing:Chongqing Univesity).
- [5] Qingyi W 2015 2015 Energy Data.
- [6] Q W M 2010 The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model *U.S: Argonne National Lab*
- [7] Feng G 2008 Research on Life Cycle Assessment and The Application in China Magnesium Industry(Beijing: Beijing University of Technology).
- [8] Rui J and Hongtao W 2010 Life Cycle Assessment of Cement in China *Chemical Engineering & Equipment* 183-7.
- [9] Di Xianghua, N. Z., et al. Life cycle inventory for electricity generation in China. *Life Cycle Ass.* 2007, 12(4): 217-224.
- [10] Yasuna M, M. B. Development of life cycle inventories for electricity grid mixes in Japan[J]. *Life Cycle Ass.* 2000, 5(5): 295-305.
- [11] Dongli W 2014 Calculation Methods on Carbon Dioxide Emission of China's Coal-fired Power Plants.(Beijing: Beijing Jiaotong University).