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Comparison Chinese Clean Coal Power Generation Technologies with Life Cycle Assessment

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Abstract

China's coal consumed by the power generation industry has caused unavoidable environmental problems in the country. Based on the methodology of life cycle assessment, this paper presents complete life cycle modeling and seven clean coal-fired power generation technologies to analyze the material consumption and environmental emissions. Incorporating up-to-date data, we give a brief economic discussion which covers the decision-making theory of the scope and come up with the future development of clean coal-fired power generation technologies.

Key words: Clean coal, Power Generation, life cycle assessment, environmental impacts

1. Introduction

Coal is responsible for 90% of the SO_2 emissions, 70% of the dust emissions, 67% of the NO_X emissions, and 70% of the CO_2 emissions. Just as Lave and Freeburg (1973) reveled that coal as the most abundant energy resource raised significant environmental problem by combustion directly, mining and transporting. China has proved a big country of energy production and consumption, and is also one of the few countries in the current world whose primary energy consists mostly of coal. However, low efficiency, unclean utilization of coal brings serious environmental pollution. Therefore, reasonable, efficient and clean exploitation of the rich coal resource, improving utilization efficiency, is the right way of exploiting clean energy in contemporary China.

Remarkably effective work about the environment optimization has been achieved. But most of these researches only consider the link of energy transformation, without a systematic appraisal of various effects in terms of life cycle. Life cycle assessment (LCA) is one of the potentially most important systematic analytical methods to determine, evaluate and improve the environmental influence in the entire life containing the raw material collection, production, and transportation. Developed countries have adopted this method to evaluate the regular power generation and recyclable energy technologies. Enrico Benetto et al. (2004) used LCA to compare six scenarios from an environmental point of view and definitively validated its usefulness in analysis and design of innovative product systems. Babbitt and Lindner (2005) introduced LCA and SimaPro software to analyze the life cycle inventory of coal electricity generation in Florida, U.S. Odeh and Cockerill (2008) developed a life cycle model to predict the energy and material requirements for UK pulverized coal power plants, In another paper they further investigated three generation technologies, namely supercritical pulverized coal (super-PC), natural gas combined cycle (NGCC) and integrated gasification combined cycle (IGCC) for decreasing life cycle GHG emissions. Chen and Xu (2010) introduced the key high efficiency combustion and advanced power generation technologies such as supercritical and ultra-supercritical technologies, circulating fluidized beds and flue gas desulphurization and NOX removal technologies. Marco et al. (2016) performed a comprehensive assessment of the energy performance of the full range of electricity generation technologies in the United Kingdom, integrating the net energy analysis (NEA) and life cycle assessment (LCA).

Life Cycle Assessment (LCA) can help decision makers to compare alternative CO_2 capture and storage technologies in a life cycle perspective. Lu and Zhang (2010) integrated conventional and economic LCA to evaluate the environmental and economic impacts of 13 crop residue conversion technologies to crop residues. Such analyses helped government to make energy strategies and policy goals related to the utilization and structuring of crop residue conversion technologies. Murat et al. (2011) developed a hybrid Eco-LCA model to quantify the emissions and account the cumulative ecological resource consumption of biomass co-firing in a coal power plant. Cui et al. (2012) conducted a life cycle assessment to estimate the environmental impact of three coal-based electricity generation scenarios (sub-critical technology, supercritical technology, and ultra-supercritical technology) in China. Xiaoye et al. (2013) show an entire life cycle modeling and a comparative assessment of current clean coal power generation technologies in China. By using up-to-date data and combining China's practical situations, this research covers all up-stream stages of the electricity life cycle before final consumption: coal extraction, coal delivery, and coal power generation. Zhao and Chen (2015) reviewed the complete life cycle modeling with advanced cleaner and generation technologies including super-critical (super-C), ultra super-critical (USC) and integrated gasification combined cycle (IGCC) and shown that the potential carbon emission would be reduced with increased generation efficiency.

Burning coal power generation makes up more than 80% of China's power production, which makes a great contribution to China's energy supply. In the rather long time to come, this kind of energy consumption structure will not change, clean coal power generation technology will spread gradually in China, evaluation in advance of its environmental influence in terms of life cycle is quite important. The objective of this paper is to analyze emission, resources consumption and the energy utilization of the whole life cycle system, we can know where exactly the major environmental impacts come from.

2. Research Scope

2.1 Research method and the definition of the life cycle chain of the clean coal.

Life Cycle Assessment is a kind of analytical tool, which is used to quantify all kinds of emissions, resources consumption, energy utilization and environmental impact factors related, in the process from raw material to final products. The life cycle includes raw material collecting and processing, transportation, sales, utilization, maintenance, and final handling, which all cause environmental disruption, in the whole life cycle system of the products, techniques and activities. Compared with traditional environmental impacts audit and assessment, LCA takes the advantage of taking all the life cycle of products into consideration, not just limited within the assessment of products processing.

Clean coal LCA includes subsystems of coal mining, transportation and generating electricity. According to various clean coal power generation routes, different routes form a few of life cycle chains. Analyzing the energy consumption and pollute emission and giving clean coal power generation technology life cycle assessments are based on LCA research outline that GB/T 24040 makes. The main research contents are as follows: recognizing and quantifying the whole life cycle of clean coal including coal and other raw material collection, washing and selecting, transportation, generating electricity, handling and emitting waste, all raw material and energy input and output as well as pollute emission related. Making an inventory assessment of clean coal power generation life cycle and comparing these life cycle chains, determining the strength and weakness of each life cycle chains.

This research involves 7 coal power generation routes:

(1) raw coal--supercritical power generation--final utilization

(2) raw coal --circulating sulfur bed--final utilization

(3) raw coal --supercritical power generation -- FGD --final utilization

(4) raw coal --coal washing and selecting --supercritical power generation--final utilization

(5) raw coal --coal washing and selecting --supercritical power generation --FGD--final utilization

(6) raw coal --regular sub critical power generation --final utilization

(7) raw coal --regular sub critical power generation --FGD --final utilization

2.2 System Margin

The purpose of this research is to figure out the share of clean coal power generation and transformed products within China in the year of 2008, and all the data is the domestic average level. The technique processes of coal power generation determine the system margin, including coal mining, washing, and selecting, transportation, generating electricity. Data lack of manufacture and retirement of all kinds of equipment and factory houses, this link is not taken into the life cycle. Lime production in desulfurization is considered. Function unit adopts 1Gj of final energy, namely 1Gj of electricity.

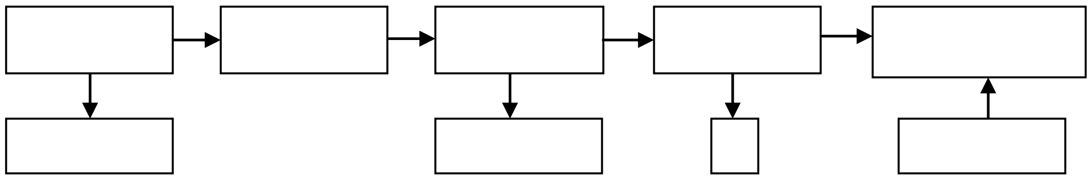

Figure 1. Life Cycle Margin of Clean Coal Power Generation

2.3 Data Source

Considering domestic average condition of coal exploitation and transportation or power generation technology, so main data are mostly from China Statistical Yearbook (2014), China Energy Statistical Yearbook (2014),China Environment Yearbook (2014) and China Transportation Yearbook (2013).All kinds of technical data of power generation technology comes from reports of every power plants in China.

Make an inventory assessment to analyze every unit process for the whole clean power generation life cycle. Considering the input and output elements of each technical phase, all technical phases and routs of clean power generation combination technologies are related to the actual calculating model. The joining and between units are calculated and analyzed with CML, a software developed by Dutch Leiden University. The data in the inventory analysis includes resources consumption (raw coal, lime, and water), energy consumption as well as pollutant emission.

3. Inventory analysis and assessment of different routes of clean coal power generation combination technologies

3.1 Energy Consumption

Table 1 shows life cycle inventory analysis of various clean coal power generation technologies. In terms of whole life cycle, energy consumption occurs not only in generating electricity unit, but through the whole life cycle, including mining, transportation and so on. As far as coal consumption is concerned, the least is supercritical method and the amount is 0~1169 tons, the most is circulating sulfide bed which consumes 0.1592 tons. Coal consumption during electricity generation stage makes up about 70% in the whole life cycle, while coal self-combustion and transportation loss occupies more than 10% (this is a waste of resources). The coal consumption in the coal mining is 8%, transportation about 4%. With the yearly decrease of steam-power vehicles, coal consumption in transportation will sharply go down. Diesel and paraffin are consumed in coal transportation, fuel oil is mostly consumed in coal transportation unit with auxiliary fuel.

Table 2 below shows the energy consumption, the efficiency for 1Gj power production and power plants' power supply efficiency. we can see in the table that among various generation routes, supercritical has the highest efficiency both in power supply within the whole life cycle and power plants' power supply power generation, which can be raised nearly by 4 percentages (life cycle efficiency) after coal washing .

Table 1 Resources Consumption and Emission for 1Gj of Electricity

In-put/output	Routs						
	Supercriti-cal	Circulating Sulfide bed	Regular Subcritical	Supercriti-cal +FGD	Regular Subcritical +FGD	Coal washing+ Supercriti-cal	Coal wash-ing Su-per-critical +FGD
Raw coal/t	0.1168546	0.159234	0.153732	0.157510	0.1582835	0.1406583	0.1465312
Water/t	1.260105	1.349265	1.302637	1.387854	1.391799	0.5793298	1.391601
Lime/kg	0	0	0	1.088427	1.33797	0	0.6357356
Fuel oil/kg	1.961398	2.168702	2.093756	2.128562	2.135276	1.983327	2.025927
Diesel oil/kg	0.777109	1.058946	1.022351	1.047478	1.05262	0.7857433	0.8185505
Gasoline/kg	1.066088	1.45273	1.402527	1.436997	1.444052	1.077933	1.12294
CO_2/kg	236.8982	336.4791	299.15	269.0032	318.7726	268.9784	283.5495

SO_2/kg	6.47453	1.148791	8.118588	0.553106	0.6237462	3.937973	0.3874272
NO_X/kg	0.784229	0.376240	0.985827	0.843239	1.021721	0.7418447	0.7711232
CH_4/kg	0.683181	0.930954	0.898782	0.921350	0.9259816	0.8223485	0.8569637
Gangue/t	0.008789	0.011870	0.01146	0.011611	0.01161115	0.02709996	0.02822293
Tailings/t	0.000669	0.000912	0.000880	0.000892	0.00089205	0.00080556	0.00083919
Solid waste /t	0.046614	0.053494	0.051645	0.052584	0.0527679	0.04976773	0.05087334
Smoke/kg	0.241271	0.442850	0.422731	0.293591	0.2705438	0.2216197	0.1484393
Dust/kg	0.009366	0.011876	0.011465	0.011718	0.01176904	0.01071292	0.01108946
Powered coal ash /kg	0.026444	0.028023	0.027054	0.027411	0.02741143	0.0267625	0.02724078
Slag/kg	0.0061171	0.006539	0.006313	0.006396	0.00639638	0.00622667	0.00634333
Other solid waste/t	0.000565	0.000664	0.000641	0.000650	0.00065006	0.00061355	0.00063073
Waste water/t	0.448780	0.485342	0.46857	0.475916	0.4773178	0.4603641	0.4695182

Table 2 Energy Consumption and Efficiency for 1Gj of Power Production

Routs	Super-critical	Circulating Sulfide bed	Regular Subcritical	Super-critical +FGD	Regular Subcritical +FGD	Coal washing+ Supercritical	Coal washing Super-critical +FGD
Energy consumption in life cycle/G_j	2.5564	3.4608	3.3412	3.4226	3.4392	3.0441	3.1694
Power supply efficiency in the whole life cycle/%	39.12	28.89	29.93	29.22	29.08	32.85	31.55
Efficiency of power plants' power supply/%	42.62	33.01	34.78	41.96	34.22	42.62	41.96

3.2 Results Interpretation

Main gas emission comes from all 5 subsystems, but mostly comes from coal self-combustion and generating electricity subsystem. CO2 is the maximum emission, 77-84% of which comes from generating electricity, about 9% is created in coal self-combustion, and coal mining makes up 3%, coal transportation 6%. For power generation technology adopting CaO desulfation technique, CO2 from lime production makes up 3%. The minimum CO2, 236 kg, is emitted in supercritical method as a result of least coal consumed , and the coal consumed in circulating sulfide bed is the most, so the CO2 emission is the largest, as much as 336 kg. From the emission inventory we know, if FGD is adopted, majority of SO2 can be reduced, while CO2 emitted is increased by about 10%. Although SO2 reduction improves environment acidification, CO2 increment worsens global warming problem.

The second largest gas emission is SO2, which is mainly in generating electricity. Among the 7 methods, regular sub critical and supercritical methods, either of which does not adopt desulphurization technique, emits respectively 8.1 kg and 6.4 kg of SO2, which both make up 98% of the SO2 emission in the whole system. With desulphurization, majority of the SO2 can be reduced, making the amount of SO2 emission go down below 0/5 kg, more than 30% of which is emitted in the coal self-combustion subsystem and of which in other subsystems is all relatively low.

Table 3 the Ratio of Emission in All Phases of Life Cycle of Clean Coal Power Generation Combination Technologies in Different Routes

Routs		Super-critical	Circulating Sulphided bed	Regular Subcritical	Super-critical +FGD	Regular Subcritical +FGD	Coal washing+ Super-critical	Coal washing Super-critical +FGD
CO_2	Generating electricity	83	84	83	77	80	83	82
	Coal self-combustion	9	8	9	10	9	9	9
	Coal transportation	6	5	6	7	6	5	5
	Coal mining	3	2	3	3	3	3	3
	Lime production	0	0	0	3	3	0	2
SO_2	Generating electricity	98	82	98	61	65	95	50
	Coal self-combustion	2	15	2	30	27	4	40
	Coal transportation	0	2	0	3	3	0	4
	Coal mining	0	2	0	3	3	0	4
	Lime production	0		0	3	3	0	2
NO_X	Generating electricity	90	71	89	87	89	87	87
	Coal self-combustion	6	17	6	7	6	7	7
	Coal transportation	3	7	3	3	3	3	3
	Coal mining	2	5	2	2	2	2	2
	Lime production	0	0	0	0	0	0	0
Smoke	Generating electricity	43	68	57	48	43	43	7
	Coal self-combustion	48	29	40	44	48	52	81
	Coal transportation	0	0	0	0	0	0	0
	Coal mining	4	3	4	4	4	5	8

Lime production	5	0	0	4	5	0	4

The third largest gas emission is NO_X and CH_4, so none of the electricity generation plants adopt denigration technique, NO_X emission is relatively high and the emission in generating electricity amounts to 78-90%, coal mining and transportation respectively 3% or some, and coal self-combustion 7%. Among the 7 methods, regular sub critical method that adopts desulphurization emits the most NO_X, as much as 1 kg (in the whole life cycle). The least NO_X, which comes from circulating sulfide bed, is 0.38 kg. Methane emission reaches 0.9 kg. Lack of data, data only in coal mining phase is counted, and the actual emission may be more.

Emission of smoke: circulating sulfide bed and regular sub critical have the highest emission, as much as 0.42 kg, smoke from coal self-combustion makes up more than 40%, while power generation technologies with FGD emits much less.

Solid waste emission is 50 kg or some, waste water emission is about 0.46 tons, 90% of which comes from generating electricity, 10% coal mining. The ecological poison is not only measured at total amount, but also is determined by the micro-scale element contained in solid waste and waste water. Lack of data, we have to generally call them solid and waste and waste water.

To make 1Gj of electricity, 1.3 tons of water is consumed, 95% of which is from generating electricity, 5% coal mining.

In terms of emission, in all the power generation life cycle chains, “raw material –coal washing-supercritical generating electricity-FGD”, has more advantage: SO_2, dust and smoke emissions are all at a quite low level. Compared with life cycle chains without washing technique “raw coal-supercritical-FGD”, lime consumption and SO_2 emission have an enormous reduction, so improving coal-washing rate is an effective way to reduce emission. After coal is washed, sulfur and ash are reduced, and gangue is picked out, sharply improving the heat efficiency of boiler, cutting down the electricity consumption for power station to make coal powder at the same time, reducing emission indirectly. Besides, there is a large amount of gangue in coal unwashed and this unwanted gangue will result in inefficient transportation and more energy consumption, thus extra emission. Energy consumption and emission for coal-washing are both low, but energy consumption and emission hold very important positions in the whole life cycle, therefore, it not only helps in environmental protection, but also save cost greatly, coal washing is a great way to make big profits at a very low cost.

4. Conclusion

Life cycle assessment has been considered as one of the most potential sustainable development-supporting tools in the 21st century. As the biggest coal consumption nation, China develops clean coal power generation technologies, reduces pollutes emission, contributing to improving not only Chinese eco-environment, but also global atmosphere environment. Aiming at the development of clean coal power generation technologies, adopting life cycle to give an overall assessment, following the whole process and analyzing quantitatively from initial raw material mining to final waste handling, Our research provides theoretical and technological support for national technological to push forward clean coal power generation technologies, and helps policy-making in future energy strategy.

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