IOP Conf. Series: Materials Science and Engineering **199** (2017) 012054 doi:10.1088/1757-899X/199/1/012054

Comparative analysis of gas and coal-fired power generation in ultra-low emission condition using life cycle assessment (LCA)

Libao Yin[1], Yanfen Liao[2*], Guicai Liu[2], Zhichao Liu[2], Zhaosheng Yu[2], Shaode Guo[2] and Xiaoqian Ma[2]

[1]Electric Power Research Institute of Guangdong Power Grid Co., Ltd., Guangzhou 510080, China
[2]School of Electric Power, South China University of Technology, Guangzhou 510640, China

*Corresponding author, e-mail: yfliao@scut.edu.cn.

Abstract. Energy consumption and pollutant emission of natural gas combined cycle power-generation (NGCC), liquefied natural gas combined cycle power-generation (LNGCC), natural gas combined heat and power generation (CHP) and ultra-supercritical power generation with ultra-low gas emission (USC) were analyzed using life cycle assessment method, pointing out the development opportunity and superiority of gas power generation in the period of coal-fired unit ultra-low emission transformation. The results show that CO_2 emission followed the order: USC>LNGCC>NGCC>CHP; the resource depletion coefficient of coal-fired power generation was lower than that of gas power generation, and the coal-fired power generation should be the main part of power generation in China; based on sensitivity analysis, improving the generating efficiency or shortening the transportation distance could effectively improve energy saving and emission reduction, especially for the coal-fired units, and improving the generating efficiency had a great significance for achieving the ultra-low gas emission.

1. Introduction

With the energy crisis and environment pollution intensified, power generation with efficiency, clean and low-carbon has gradually become China's energy development strategies. In June 2015, China submitted Intended Nationally Determined Contributions (INDC), proposing that carbon intensity would be reduced by 60%-65% in 2030, compared to that in 2005. Due to its clean and efficiency characteristics, gas power generation developed rapidly with the government supports in recent years. As predicted in BP energy outlook (2016 edition), China's energy mix continues to evolve with coal's dominance declining from 66% in 2014 to 47% in 2035 and natural gas more than doubling to 11%.

At present, natural gas combined cycle power generation (NGCC), liquefied natural gas combined cycle power generation (LNGCC) and natural gas combined heat and power generation (CHP) are the main modes of nature gas generation. As the ultra-low emission standard was promulgated in 2014, requiring the emission of SO_2, NO_X and dust respectively below 35 mg/Nm^3, 50 mg/Nm^3 and 5 mg/Nm^3 in coal-fired unit, China's coal-fired generation will be dominated by ultra-supercritical power generation (USC) with ultra-low emission.

IOP Conf. Series: Materials Science and Engineering **199** (2017) 012054 doi:10.1088/1757-899X/199/1/012054

The previous studies show that gas power generation had superiorities in pollutant emission compared with coal-fired generation[1-4]. However, there are rare literatures mentioning the comparison between nature gas generation and coal-fired generation in the ultra-low emission condition. Therefore, it is necessary to further discuss if the nature gas generation has the superiority in energy saving and emission reduction compared with USC with ultra-low emission technology, providing the basic data for the policy making and the technology selection of enterprises.

2. Methodology

2.1. Research subjects
According to the status of gas turbines in China, 9F-level NGCC unit with 390 MW, 9F-level LNGCC unit with 390 MW and 9E-level CHP unit with 180MW was selected to analyze their energy consumption and emission. For USC, an 1000MW coal-fired unit with ultra-low emission was selected. The basic parameters were set and shown in Table 1.

Table 1. The basic parameters of generator set

Types of units	NGCC	LNGCC	CHP	USC
model	M701F	M701F	PG9171E	/
Heat efficiency (%)	55%	55%	66%	42.37%[a]
Annual generating hour (h)	3500	3500	3500	5259
Annual electric production (kWh)	1.365 billion	1.365 billion	0.57 billion	5.259 billion
Annual fuel consumption	$0.25\times10^9 m^3$	$0.25\times10^9 m^3$	$0.132\times10^9 m^3$	1.523×10^9 kg
Operating year (a)	30	30	30	30

[a] Calculated by the coal consumption for power generation of 0.29 kg/kWh.

2.2. System boundary
The function unit was 1 kWh, and the energy consumption and emission were calculated in the generation of 1 kWh. The power generation systems included the following stages: (1) fuel mining and processing, (2) fuel transportation, (3) station building, (4) operating and retirement. The system boundary of these four generation technologies was shown in Fig.1.

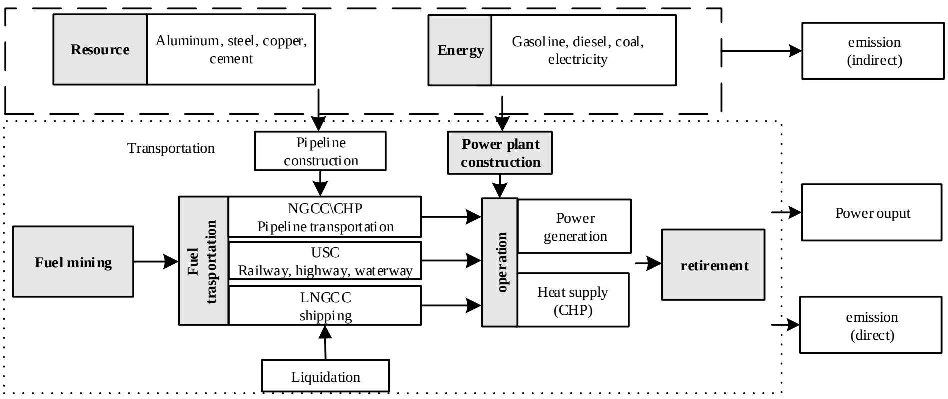

Figure 1. The system boundary of NGCC, LNGCC, CHP and USC generation technologies

3. Unit process and life cycle inventory

3.1. Data source and assumptions
Based on the researches and the status of electricity production, the following assumptions were made to simplify the calculation of different power generation technology:(1) The emission from the building of liquidation station and the manufacture of vehicles were ignored. (2) The average distance of pipeline transportation was 519 km, and the shipping distance of LNG was 1781 km [5]. (3) the

ratio of railway, waterway and highway was set to 60%, 25% and 15%, respectively[6]. (4) The secondary emission from steel manufacture and transportation were only considered in the gas pipeline building. Data source of each stage were shown in Table 2.

Table 2. Data source of each stage.

Unit Process	Item	Data source
Fuel mining and processing	Gas mining and liquidation	[5], [7]
	Coal mining and washing	[8]
Fuel transportation	Gas transportation	[9]
	Gas pipeline building	[5], [10]
	Coal transportation	[6], [5, 11]
Power station building and retirement	Building materials consumption	[12]
	Building materials transportation	[5, 11]
	retirement	[6]
Power station operation	Gas power generation	[13], [14]
	Coal-fired generation	[15, 16]

3.2. Indirect energy consumption and emission
In the stage of fuel mining, transportation, power plant construction and retirement, building materials like steels, cements, coppers, aluminums were needed. This part of emission from the use of raw materials belonged to indirect emission, while the emission from those five processes belonged to direct emission. Energy consumption and emission of each material was referred to China's statistic data in industries [9, 12, 17].

3.3. Unit process
In fuel mining and processing, through seismic exploration, well drilling, workover, gas field gathering and purification, nature gas was sent to the main pipeline. Nature gas was mainly processed by liquidation, and the cascade refrigeration and the mixing refrigeration were the main liquidation techniques. Coal was mainly processed through washing, and coal jigging was the main method. In Fuel transportation process, steel production and transportation were the main considerations in the gas pipeline building. LNG was transported by shipping. Coal transportation included railway, waterway and highway. The inventory at construction stage was mainly from the production and transportation of equipment and building materials, and the energy consumption and emission of installation could be ignored. Energy consumption and emission of retirement were estimated as 10% in power plant construction [6]. As for the operation process, in USC with ultra-low emission, since the real emission concentration in operation was closed to the ultra-low emission standard, the emission concentrations of SO_2, NO_X and dust were set to 35, 50 and 5 mg/Nm^3 respectively.

3.4. Analysis of inventory
Energy consumption and gaseous emissions of each stage in four kinds of power generation system were shown in Table 3, where all the energy consumptions were converted into the one-time energy of standard coal, nature gas and diesel. Energy consumption and CO_2 emission were on the following order: USC > LNGCC > NGCC > CHP. CO_2 emission of each kind of power plant was 773, 461, 416 and 408 gCO_2/kWh, respectively, due to the higher generating efficiency of gas power generation at the operation stage.

Due to the higher efficiency and the characteristics, NO_X, SO_2 and dust of gas power generation were still lower than those of USC with ultra-low emission, in total. For NO_X, its emission was on the following order: LNGCC>USC>NGCC>CHP. Due to the ultra-low emission standard, the proportion of NO_X emission in the operation stage was low, and NO_X emission was more greatly decided by fuel mining and transportation.

Table 3. Energy consumption and pollutant emissions of electricity generation (1 kWh)

stages	mode	Coal	Diesel	NG	CO_2	CH4	NO_X	SO_2	PM	CO
FMP[a]	NGCC	10.9	6.53	0.007	42	0.44	0.312	0.001	0.076	0.496
	LNGCC	11.4	6.53	0.026	42	0.44	0.312	0.001	0.076	0.496
	CHP	10.7	6.41	0.006	41	0.44	0.306	0.001	0.075	0.487
	USC	12.9	0.45	0	41	3.26	0.269	0.285	0.128	0.037
FT[b]	NGCC	3.4	0.59	0.006	2	0.01	0.021	0.006	0.008	0.005
	LNGCC	0	1.64	0	47	0.75	0.255	0.11	0.046	0.01
	CHP	2.3	0.39	0.004	1	0.01	0.021	0.006	0.007	0.005
	USC	1.8	2.25	0	12	0	0.227	0.136	0.017	0.037
PPCR[c]	NGCC	0.6	0.01	0.182	2	0.07	0.012	0.018	0.047	0.062
	LNGCC	0	0.01	0.182	2	0.07	0.012	0.018	0.047	0.062
	CHP	0	0.01	0.179	1	0.05	0.009	0.013	0.034	0.045
	USC	0.5	0.03	0	1	0	0.003	0.006	0.026	0
PPO[d]	NGCC	0	0	0.182	371	0.03	0.143	0	0.006	0.009
	LNGCC	0	0	0.182	371	0.03	0.143	0	0.006	0.009
	CHP	0	0	0.179	364	0.03	0.14	0	0.006	0.445
	USC	289	3.11	0	720	0.01	0.182	0.116	0.017	0.142
Total	NGCC	14.9	7.16	0.195	416	0.55	0.488	0.025	0.137	0.573
	LNGCC	12	8.21	0.208	461	1.29	0.721	0.129	0.175	0.577
	CHP	13.5	6.83	0.19	408	0.52	0.476	0.02	0.122	0.981
	USC	305.0	5.85	0.000	773	3.27	0.681	0.542	0.189	0.217

[a]FMP: Fuel mining/processing; [a]FT: Fuel transportation; [a]PPCR: Power plant construction/retirement; [a]PPO: Power plant operation.

4. Impact assessment

4.1. Energy consumption

Gas power generation had a higher efficiency than coal-fired generation, thus the consumption of one-time energy was lower. However, the scarcity of coal and nature gas was different, and resource consumption of them should be determined through normalization and weighting analysis.

Table 4 shows the one-time resource consumption for generating 1 kWh electricity. After normalization and weighting analysis, the resource consumption of coal-fired generation was lower than that of gas power generation by 47%-52%. Therefore, China’s electricity production should still base on coal-fired power generation, supplemented by the cleaner ways like gas power generation, which was mainly for peak shaving.

Table 4. One-time resource consumption for generating 1 kWh electricity

	NGCC			LNGCC			CHP			USC		
	SC[a]	DS[b]	NG[c]	SC[a]	DS[b]	NG[c]	SC[a]	DS[b]	NG[c]	SC[a]	DS[b]	NG[c]
WR[d]	1.53 E-04	2.81 E-04	6.13 E-03	1.23E-04	3.22E-04	6.54E-03	1.38E-04	2.68E-04	5.96 E-03	3.12 E-03	2.30 E-04	7.39 E-12

Total	6.57E-03	6.99E-03	6.36E-03	3.35E-03

[a]SC: Standard coal; [b]DS: Diesel; [c]NG: Nature gas; [a]WR: Weighted resource consumption.

5. Environment impact assessment

The emission inventory was arranged into five environmental impact categories of global warming (GW), acidification (AC), nutrient enrichment (NE), photochemical ozone formation (PO) and soot and ashes (SA). Based on the characterization benchmarks in 2000 [18], the environment impacts of characterization were calculated. Considering difference importance among those environmental impacts, normalization and weighting step was conducted. The weighted environmental potential (WP(*j*)) was calculated by the following formula:

$$WP(j)=\frac{EP(j)}{T\cdot ER(j)}WF(j) \tag{1}$$

where, EP(*j*) was the environmental potential of impact category *j*; *T* was the expected lifetime; ER(*j*) was the normalization reference of impact *j*; WF(*j*) was the weighting factor of impact *j*.

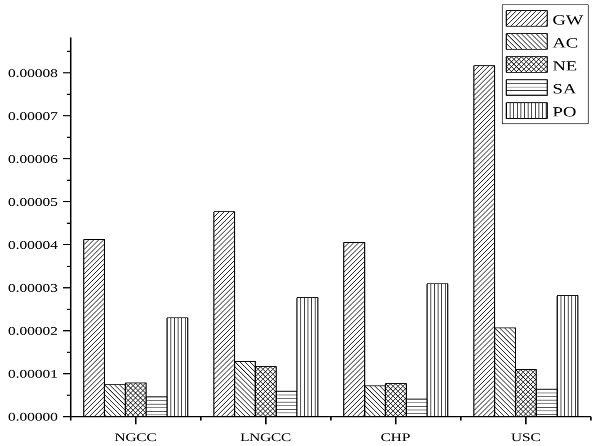

Figure 2. The weighted environmental potentials for each impact in the life cycle

Figure 2 shows the weighted environmental potentials for each impact in the life cycle of power generation. Global warming had greatest impacts, accounting for 48.97%, 45.05%, 44.85% and 55.24% of total, respectively. PO had secondly greatest impacts, accounting for 27.32%, 26.17%, 34.17% and 19.04% of total respectively. Therefore, in the condition of ultra-low emission, global warming was the most important environment impact, and enhancing the control and management of CO_2 emission would become an important development direction for power generation in the future.

6. Sensitivity analysis

When the generation efficiency changed by 2%, as well as the transportation distance changed by 20%, the rate of gaseous emissions change in power generation were shown in Figure 3 and Figure 4. Compared to gas power generation, coal-fired generation was affected by generation efficiency more greatly. That was because the coal-fired generation had a higher proportion in the operation emission and a lower ratio in the transportation than gas power generation. Therefore, for ultra-supercritical unit with ultra-low emission, promoting the generation efficiency had a greater significance.

IOP Conf. Series: Materials Science and Engineering **199** (2017) 012054 doi:10.1088/1757-899X/199/1/012054

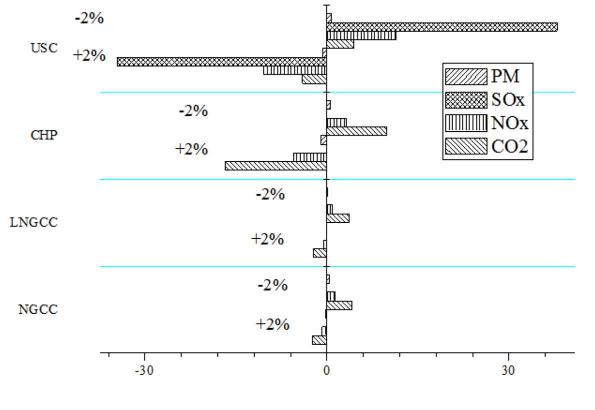

Figure 3. Impacts of power generation efficiency on environmental emissions (%)

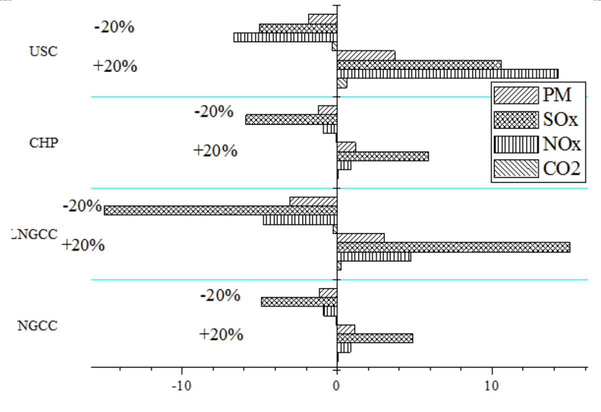

Figure 4. Load distance impact on gaseous emissions (%)

7. Conclusion

The results show that CO_2 emission followed the order: USC (773.35 gCO_2/kWh) > LNGCC (461.18 gCO_2/kWh) > NGCC (416.03 gCO_2/kWh) > CHP (407.95 gCO_2/kWh); the resource depletion coefficient of coal-fired power generation was lower than that of gas power generation, and the coal-fired power generation should be the main part of power generation in China; improving the generating efficiency or shortening the transportation distance could effectively improve energy saving and emission reduction, especially for the coal-fired units, and improving the generating efficiency had a great significance for achieving the ultra-low gas emission.

Based on the Results, China should remain the predominant role of coal-fired generation and strongly support the gas power generation, especially in ultra-low emission conditions. Due to the higher cost in gas power generation and significant impact of fluctuations in gas prices, the government should still support the gas power generation by a series of policies like subsidy. In any case, taking large coal-fired generation as dominant, eliminating medium and small-sized coal-fired power plants and promoting the proportion of gas power generation is the inevitable trend of China’s power generation development. Therefore, using gas power generation to replace the small-sized coal-fired power plants can be the development direction in the next few years.

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).

References

[1] Hondo H 2005 Life cycle GHG emission analysis of power generation systems: Japanese case *Energy* **30** 2042-56

[2] Jaramillo P, Griffin W M and Matthews H S 2007 Comparative life-cycle air emissions of coal, domestic natural gas, LNG, and SNG for electricity generation *Environmental Science & Technology* **41** 6290-6

[3] Dones R, Zhou X and Tian C 2004 Life Cycle Assessment (LCA) of Chinese energy chains for Shandong electricity scenarios *International Journal of Global Energy Issues* **22** 199-224

[4] Burnham A, Han J, Clark C E, Wang M, Dunn J B and Palou-Rivera I 2011 Life-cycle greenhouse gas emissions of shale gas, natural gas, coal, and petroleum *Environmental Science & Technology* **46** 619-27

[5] 2014 *China Statistical Yearbook-2013* (Beijing: China statistics press)

[6] Jing-yao L, Yu Q, Xiu-xi L and Zhi-xian H 2009 Life cycle assessment of coal-fired power generation and its alternatives *JOURNAL OF CHINA COAL SOCIETY* **34** 133-8
[7] Q W M 2010 The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model *U.S: Argonne National Lab*
[8] Bureau J P S 2012 A brief analysis of Jilin Province key monitoring energy-intensive products for energy consumption per unit product in 2011.
[9] Qi Z 2008 Study of life cycle energy consumption, enviromental emission and economics of biodiesel. (Shanghai: Shanghai Jiao Tong University)
[10] 2008 The second West-to-East gas pipeline pull the steel pipemaking Industry to leap again. (Oil Daily
[11] Bureau G P 2011 Notice of improving feed-in tariff of coal fired power plants.
[12] Yongkui Y 2005 Energy system assessment and carbon reduction strategy research based on exergy analysis of life cycle. (Guangzhou: South China University of Technology)
[13] Nan-xing G 2011 Power Plant Catalogue of Domestic Gas Turbines *POWER EQUIPMENT* **25** 203-12
[14] Zhixian H 2007 Systematic Analysis and Evaluation of Chemical Energy Products in Natural Gas Industry. (Guangzhou: South China Univesity of Technology)
[15] Junmin W 2011 The Life Cycle Assessment of Coal-fired Power Generation. (Taiyuan: Taiyuan University of Technology)
[16] Rui J and Hongtao W 2010 Life Cycle Assessment of Cement in China *Chemical Engineering & Equipment* 183-7
[17] Qingyi W 2015 2015 Energy Data.
[18] Yang J-x and Nielsen P H 2001 Chinese life cycle impact assessment factors *Journal of Environmental Sciences* **13** 205-9