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LIFE CYCLE COMPARISON ASSESSMENT OF COAL-BASED POLYGENERATION AND SEPARATE PRODUCTION

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ABSTRACT

The Chinese government has promised to cut carbon dioxide emission per unit gross domestic product by 60 to 65 percent by 2030, compared with the 2005 level. Moreover, it's highly outlined that the comprehensive utilization of coal resources is a crucial way to reach this goal in the latest energy development plans. Accordingly, we conducted a life cycle comparison assessment of a coal-based polygeneration system and separate production systems. The polygeneration system can generate electricity, gasoline, diesel, liquefied natural gas (LNG), sulfur, benzene, hydrogen, carbon monoxide and ammonia sulfate simultaneously. Moreover, some representative separate production systems have been carefully selected for the comparison study. The life cycle results indicate that the current polygeneration system can reduce global warming potential (GWP) by 26.5 percent, acidification potential (AP) by 53.1 percent, eutrophication potential (EP) by 53.7 percent, photochemical ozone creation potential (POCP) by 49.1 percent, and ozone depletion potential (ODP) by 20.4 percent, respectively, compared with representative separate production processes. As a result, this study may also demonstrate the potential advantages to develop coal-based polygeneration systems in China.

Keywords: life cycle assessment, polygeneration, separate production, inferior coal utilization

NONMENCLATURE

Abbreviations	
LCA	Life Cycle Assessment
GWP	Global Warming Potential
AP	Acidification Potential
EP	Eutrophication Potential
POCP	Photochemical Ozone Creation Potential
ODP	Ozone Depletion Potential
GHGs	Greenhouse Gases

1. INTRODUCTION

Coal is the most important energy resources in China. The coal consumption occupied 62 percent of the whole energy consumption of China in 2016. The recoverable coal of China in 2016 was 80.2 thousand megatons; the lignite and sub-bituminous shared 45.7 percent of the total reserves. Moreover, most kinds of coal in China, especially inferior coal, are not suitable to be directly applied to integrated coal gasification combined cycle (IGCC) [1]. Growing energy shortage and environmental problems are urging China to use coal more effectively. Coal-based polygeneration may be a feasible way [2], and it has also been highly emphasized in the latest national energy development plans of China. However, this technology still needs plenty of research, especially on environmental benefits aspect.

Life cycle assessment method (LCA) is widely used to analyze the environmental influence of different energy systems for its advancement. Jaramillo et al. indicated that coal-based and natural gas-based liquid fuel production were stronger sources of greenhouse gases (GHGs) than conventional petroleum industry [3]. Li et al. discovered that heat supply by coal-based synthetic natural gas, in place of coal, only diverted pollutants from the load center to the production center [4]. Singh et al. revealed that carbon capture and storage (CCS) might also bring some negative effects like eutrophication [5]. Compared with these advanced energy systems, coal cascade utilization may be a mild way to realize the clean energy plan.

However, it's difficult to evaluate a system outputting different types of products. When a system generates various products, the most commonly used method is to normalize products output by using mass-based, market value-based, energy-based and exergy-based allocation method [6–8]. However, such an allocation procedure may cause a great difference. The other way is to extend or add a comparison system to use the complete products output as the function unit. This method is valuable if appropriate comparison production routes are selected [9]. However, current LCA studies have hardly covered the direct comparison analysis of polygeneration and separate production processes due to the huge inventory data demand. To partially fill the research gap, we conduct a life cycle assessment of a coal-based polygeneration system (retrofitted from a sub-critical power plant) and compare the LCA results with common separate production processes. As a result, the study is expected to evaluate the environmental optimization potential of coal-based polygeneration system form a social level.

2. MATERIAL AND METHODS

2.1. Polygeneration plant layout

The current coal-based polygeneration plant is retrofitted from a sub-critical power plant with a circulating fluidized bed (CFB) boiler. Moreover, the inlet coal is typical inferior coal, whose lower heating value is only 14.515 MJ/kg. A fluidized bed pyrolysis stove is placed next to the CFB boiler so that fresh coal can be firstly fed from it. The generated coke after pyrolysis is conveyed to the CFB boiler to produce electricity. During pyrolysis, some harmful elements in coal, including sulfur, chlorine and nitrogen, are released and then utilized. The crude pyrolysis gas mainly includes methane, hydrogen, carbon monoxide, benzene, coal tar and so on. The mixture will be separated and converted into target products in the succedent processes. Gasoline and diesel are generated

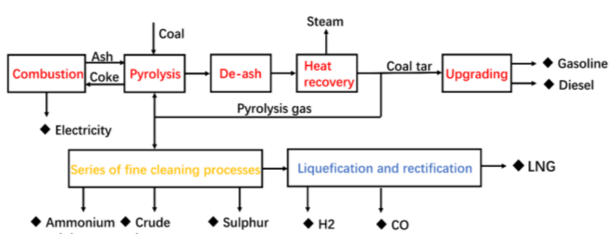

Fig. 1. The schematic technological route diagram of the polygeneration system.

by hydrogenation of coal tar. The polygeneration system consumes 340 tons of coal per hour while producing 300 megawatt-hours of electricity. Other products output can be calculated according to Table 1 in proportion. The main technological route is illustrated in Fig. 1.

2.2. Separate production systems

To evaluate the environmental optimization potential of the polygeneration system, typical separate production systems corrected by technology average are selected. The comparison principle of separate production and polygeneration is also illustrated in Fig. 2, in which the two comparison systems provide the same products. However, all separate production plants directly exchange neither matter nor energy with each other, which is quite the opposite of polygeneration.

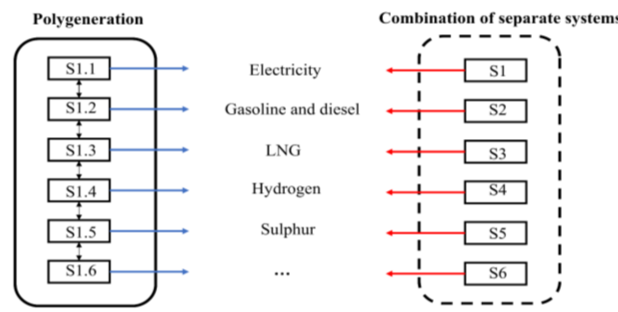

Fig. 2. The comparison principle between polygeneration and separate production.

2.2.1. Electricity generation

A sub-critical power plant, with a primary stream temperature of 538 ℃ and a primary stream pressure of 17.4 MPa, has been selected for comparison. It is also the predecessor of the polygeneration plant. Moreover, the same inferior coal and environmental protection devices, as these of the polygeneration plant, are used in the power plant. The net energy efficiency of electricity production is 33.1 percent, which is a common efficiency value of sub-critical electricity production.

2.2.2. Gasoline and diesel production

The traditional petroleum industry has been selected as the comparison scenario of gasoline and diesel production [10].

2.2.3. Liquefied natural gas (LNG) production

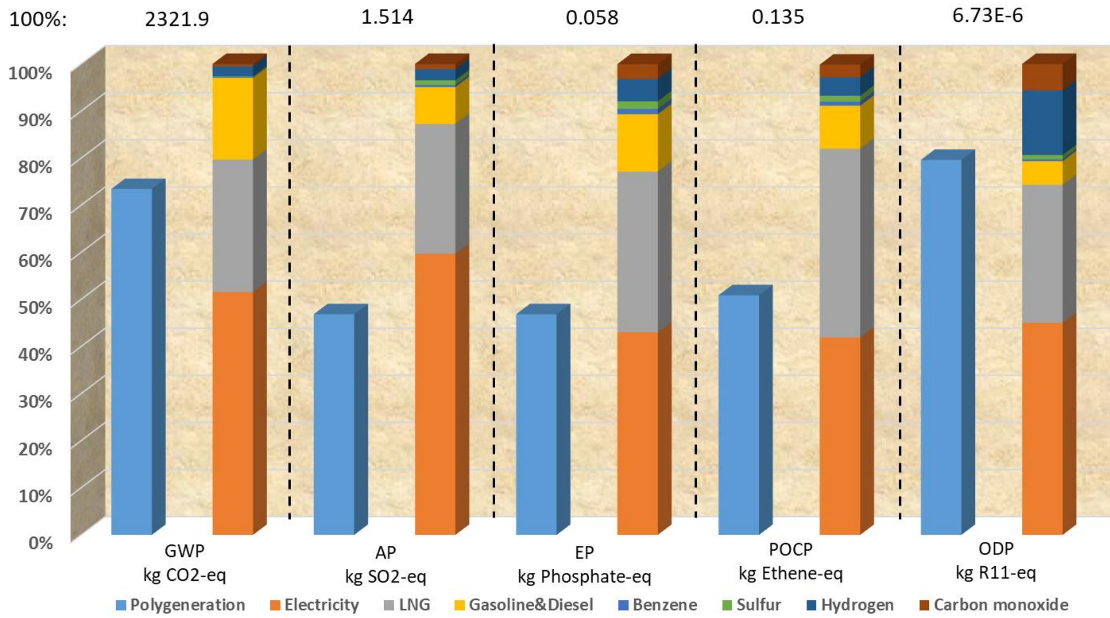

Fig.3. LCA comparison results of the polygeneration system and combination system. The upper values are the absolute life cycle impact category values of combination system, which are esteemed as 100 percent in comparison.

The natural gas industry has been used to provide natural gas, which is then liquefied to generate LNG [10].

2.2.4. Hydrogen and carbon monoxide production

In the polygeneration plant, hydrogen and carbon monoxide have been separated after liquefication and rectification. Therefore, steam reforming of heavy fuel oil to get hydrogen and cryogenic separation of syngas to get carbon monoxide are used as comparison routes [10].

2.2.5. Sulfur production

Petroleum-based sulfur production has been regarded as the comparison route [10].

2.2.6. Benzene production

Benzene production by technology mix at producer is selected as the comparison route [10].

2.3. Inventory data collection

A hybrid life cycle inventory collection method has been used through the study, which mainly includes process flow-based and input-output based collection way. The LCA study of polygeneration is based on an actual transformation project, and the operation data of polygeneration (Section 2.1) and electricity production (Section 2.2.1) is primary. The inventory data of separate production of benzene, sulfur, gasoline and diesel is directly extracted from Gabi life cycle database [10]. The inventory data of technology average at producer is preferred. In addition, the result correction will be discussed in Section 3.

2.4. Function unit

A 'Cradle-to-Gate' model is employed in the LCA study. The function unit is all products output normalized by one megawatt-hour of electricity output of the polygeneration system, and it is also summarized in Table 1.

Table 1. The function unit used in the LCA study.

Products	Unit	Value
Electricity	MWh	1
Gasoline	kg	8.88
Diesel	kg	22.57
Sulfur	kg	5.44
Benzene	kg	1.92
Hydrogen	kg	3.42
Carbon monoxide	kg	24.42
LNG	kg	58.00

3. RESULTS AND DISCUSSION

3.1. Life cycle impact assessment (LCIA)

CML 2001 method has been used for life cycle impact assessment. Five common categories, including GWP, AP, EP, POCP and ODP, have been evaluated in detail. The life cycle comparison results are depicted in Fig. 3. In the subsequent analysis, the optimization capacity of polygeneration is defined as the life cycle impact category difference between the combination of separate production and polygeneration.

3.2. Global Warming Potential (GWP)

Coal-based production processes are strong sources of carbon dioxide emission. In this case, the coal-based polygeneration system will show no noticeable advantage to control GWP if comparative liquid fuel (gasoline, diesel and LNG) production are derived from the petroleum industry and natural gas industry. Considering that coal-based liquid fuel production process is more suitable to evaluate the optimization potential of polygeneration, we use 273.5 kg CO2-eq/GJ coal-based liquid fuel to correct it [11]. As a result, the polygeneration system can reduce 26.5 percent of GHGs compared with the combination of separate production systems. It mainly benefits from the high energy efficiency of coal cascade utilization, in which we pursue not the maximum yield of a single product but the comprehensive benefits.

3.3. Acidification Potential (AP)

In the polygeneration process, fifty percent of sulfur in coal is firstly converted into hydrogen sulfide in the pyrolysis stove and then converted into sulfur. Moreover, seventy percent of nitrogen is also released in the pyrolysis stage. Therefore, the coke combustion, used to generate electricity, produces fewer acid emissions, which is the key of acid emissions reduction. Moreover, the transportation process is somewhat avoided in the polygeneration system. As a result, the polygeneration system miraculously reduces 53.1 percent of acid emissions.

3.4. Eutrophication Potential (EP)

Eutrophication emissions are from both gaseous emissions and effluents. Frequent transportation, by diesel-powered trucks or electricity-powered trains, is in great demand in the separate production systems. Therefore, transportation is also an important source of nitrogen oxides (NOx) in separate production systems. However, NOx is limited to generate due to the first pyrolysis process of coal and partly avoided transportation in the polygeneration; effluents can also be pretreated in the polygeneration plant by various methods. For example, wastewater containing large amounts of organic chemicals is conveyed to combust in the CFB boiler. Consequently, cleaner fuel, less transportation and various pretreatment methods are responsible for the great optimization capacity of polygeneration for EP, which reaches 53.7 percent in this case.

3.5. Photochemical Ozone Creation Potential (POCP)

Photochemical ozone creation is mainly induced by ozone precursors and some catalysts. The ozone precursors include some volatile organic compounds (VOCs). Some nitrogen oxides can also act as the catalyst to generate ozone. Therefore, NOx reduction is beneficial to control POCP. In addition, volatile organic emissions, mainly from the coal mining process, are crucial to POCP. Therefore, the optimization capacity of polygeneration for POCP, reaching 49.1 percent, benefits from less volatile organic emissions and NOx reduction. However, we also used some non-coal-based processes as comparison routes for data availability in the combination system, which may underestimate the POCP optimization effect of polygeneration.

3.6. Ozone depletion potential (ODP)

Ozone depletion increasingly gets attention as most countries have promised to control it. Among various emission sources of ozone depletion, coal mining is the most concentrated source, which directly limits the optimization capacity of polygeneration for ODP-only 20.4 percent. Moreover, nitrous oxide (N2O), generated in the combustion process at relatively low temperature, also has a bad influence on ODP. Moreover, we can’t emphasize the importance of social efforts to control ozone destruction too much.

3.7. Validation of current results

Due to the originality of the current polygeneration technology, similar LCA studies (comparison between polygeneration and separate production) are difficult to be found to fully check current results. Fortunately, Śliwińska et al. performed a life cycle greenhouse gases evaluation between cogeneration (electricity and methanol) and separate production, which revealed that cogeneration would reduce about 17.6 percent to 23.9 percent of GHGs, compared with the combination of separate production [9]. The value (17.6%-23.9%) is comparable to ours (26.5%), and it may also partially demonstrate the reasonability of the current study.

4. CONCLUSIONS

In conclusion, we compare the life cycle performance of the coal-based polygeneration system and separate production systems, and the results indicate that polygeneration has varying degrees of optimization capacity for life cycle impact categories. In general, the following points may be the potential reasons to distinguish polygeneration. Firstly, the transfer of matter and energy among different subsystems, within the polygeneration system, almost realizes self-supply of various forms of energy. For example, electricity, steam and heat are easily supplied to subsequent processes. Secondly, from an economic perspective, the scale effect of centralized treatment of pollutants makes it possible to locally employ more advanced control technologies. Thirdly, the efficiency of polygeneration system can be improved greatly by optimizing the cooperation of different subsystems. The energy efficiency of the current polygeneration system is 15.7 percent higher than that of the power plant using the same coal. However, it's also expected to compare the life cycle performance of coal-based polygeneration and separate coal-based production processes, which may reveal its greater environmental optimization potential.

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