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Cost combined life cycle assessment of lignite-based electricity generation

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HIGHLIGHTS

- Cost coupled LCA of lignite-based electricity generation scenarios are quantified.
- Coal-based electricity generation is used as control.
- The efficiency of energy consumption is a key to reduce environmental impact.
- Environmental burden generated from lignite-based scenarios are high.
- Pre-drying with steam-based technology is suitable.

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ABSTRACT

Life cycle assessment and life cycle costing were carried out to identify the environmental and economic burdens of six lignite-based electricity generation scenarios. Coal-based electricity generation is used as control. Results showed that diesel consumption for road transport, energy (i.e., electricity and steam) consumption for lignite drying, and the use of coal/lignite had dominant contributions to overall environmental and economic burden. Direct heavy metal and dibenz(a,h)anthracene emissions form electricity generation represented an additional important role to the total environmental effect for all scenarios. Lignite drying with steam drum and steam fluid bed scenarios present higher economic benefits than the coal-based scenario, whereas their environmental burden is higher than that of the coal-based scenario. Results indicate that lignite drying with microwave, tube type, and rotary drum technologies are unsuitable for lignite utilization in terms of cost and environmental views.

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1. Introduction

Lignite is a soft brown combustible sedimentary rock that is generally considered the lowest rank of coal because of its high water content and relatively low energy density. The estimated recoverable reserves of lignite are equivalent to 22.5% of known world coal reserves [1]. Currently, lignite is mined worldwide (e.g., Europe, China, India, Russia, United states) and used for electricity generation. For instance, approximately 1042 million tons (Mt) of lignite are currently produced worldwide, which accounts for 13.3% of the global coal production [2]. Compared with lignite reserves, lignite utilization is low because of the potential risk of spontaneous combustion and inefficient transport caused by its high volatile matter and water content. As energy demand, consumption, and cost increase, countries worldwide focus on methods that will advance the use of lignite through various upgrading technologies such as pyrolysis [3,4], gasification [5], and drying [6–8]. Unlike hard coal-based energy production, additional raw materials and energy inputs for lignite upgrading may present serious environmental pollution. Therefore, systematically quantifying pollutants generated from lignite utilization, as well as determining their environmental and economic effects and identifying the key factors for improvement via an effective approach, is highly needed.

Life cycle assessment (LCA) and life cycle costing (LCC) are effective and systematic approaches for quantifying the environmental and economic improvements associated with the whole life cycle stages of a product, process, or activity [9,10]. The environmental impact of lignite utilization has been extensively studied

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via LCA [11–16]. Volkart et al. [11] have reported an LCA comparing the environmental performances of lignite-, hard coal-, natural gas- and wood-based electricity generation during integrated gasification combined cycle power plants in Europe for 2025 and 2050 with and without carbon capture and storage. Çetinkaya et al. [12] analyzed the environmental impact of lignite-based steam production in Turkey. Skodras et al. [13] evaluated the environmental burden caused by the co-utilization of waste wood with lignite trials at industrial boiler, whereas Theodosiou et al. [14] and Georgakellos [15,16] quantified the environmental impact generated from power plants in Greece. However, few studies have conducted LCC analysis of lignite utilization. In addition, no studies conducted via LCA on lignite utilization in China, where is well known as one of the largest energy consumers and emitters of greenhouse gases worldwide. The environmental performance of lignite utilization in China is quite important to the worldwide environmental protection. Moreover, there is a lack of information regarding the comparison across various lignite dying technologies. The cost combined environmental effects of lignite upgrading technologies need be identified to provide policymakers with useful information. Our goals are as follows: (1) to quantify the environmental and economic effect of lignite drying, which is one of the most used lignite upgrading technologies; (2) to encourage right decisions for the efficient use of lignite; (3) to identify the key factors for energy saving and pollution control; (4) to introduce a Chinese database of lignite-based electricity generation with and without lignite drying pretreatment; and (5) to compare the environmental and economic performance of lignite-based electricity with those in other parts of the world.

2. Scope definition

2.1. Functional unit and system boundary

In this study, 1 kW h electricity generation is chosen as the functional unit, which is a comparison unit in a life cycle inventory. System boundary is established through the cradle-to-gate approach (Fig. 1). Coal-based electricity generation (S-1), lignite-based electricity generation (S-2), lignite-based electricity generation with microwave drying (S-3), lignite-based electricity generation with superheated steam fluid bed drying (S-4), lignite-based electricity generation with superheated steam drum drying (S-5), lignite-based electricity generation with tube type drying (S-6), and lignite-based electricity generation with rotary drum drying (S-7) were considered in this study. These scenarios involve direct air emissions (e.g., carbon dioxide, carbon monoxide, methane, sulfur dioxide, particulates, nitrogen oxides, heavy metals, and polycyclic aromatic hydrocarbons), infrastructure, raw materials production, road transport, electricity generation, and waste disposal. For all scenarios except for S-1 and S-2, the additional process involved lignite drying.

2.2. Methodology

The economic effects of each scenario are assessed by using the LCC method, which is similar to LCA but considers cost instead of environmental effects [17,18]. For each life cycle process, the quantities per functional unit of waste amount, energy consumption, and use of raw materials are listed. The inventory is combined with the cost database (i.e., market price of raw materials, energy, transport, labor, infrastructure, waste disposal, and maintenance) to evaluate the LCC. The current market price of wastewater treatment (0.24 $/m^3) is used. The price of raw materials and energy based on the current Chinese market was used in this study (based on the November 25, 2014 exchange rate of USD 1.00 = 6.14Yuan). The power plant infrastructure lifetime considered in this study is 30 years.

The life cycle impact assessment (LCIA) results are calculated at mid-point level using ReCiPe H method [19,20], because this model is one of the most widely used models in LCA analysis. In addition, the ratio of the impact per unit of emission divided by the per capita world impact for the year 2000 is used to determined normalization [21] for analyzing the respective share of each midpoint impact to the overall impact. To check the robustness of the obtained LCIA results, TRACI [22], and IMPACT2002+ [23] methods are used as comparison.

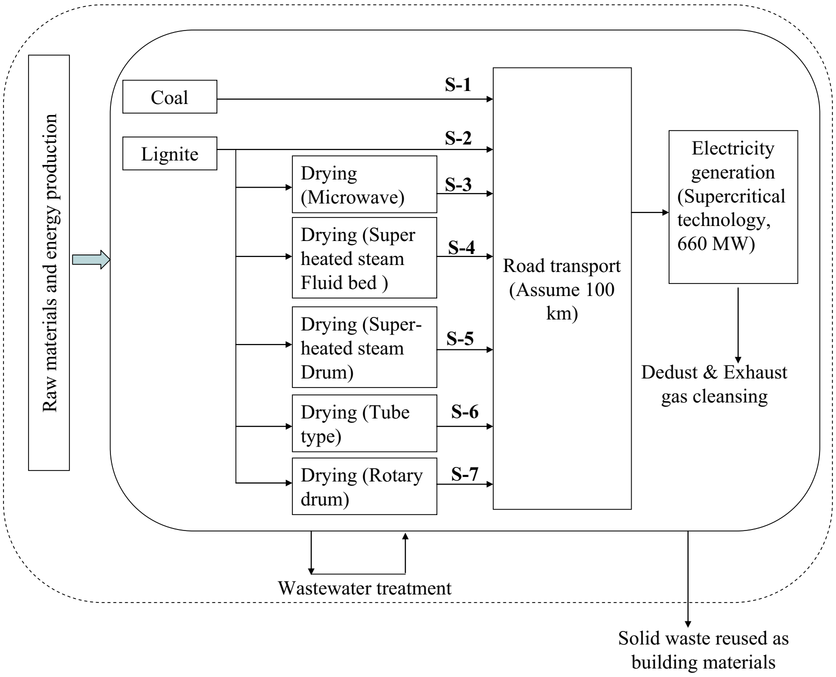

Fig. 1. System boundary.

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