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Comparative life cycle assessment of regional electricity supplies in China

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ABSTRACT

In this study, we conducted a life cycle assessment (LCA) of the power sector in 31 provinces in China, with a focus on five major types of power (namely, thermal power, hydropower, solar photovoltaic power (solar power), nuclear power, and wind power). The scope of the life cycle included resources extraction, processing, infrastructure construction, power generation, and transmission. Key results include the following. (1) There are differences in the life cycle global warming potential (GWP) of the five power sources at the national level. In particular, thermal power discharges 19, 66, 123, and 164 times more emissions than solar power, hydropower, wind power, and nuclear power, respectively. (2) There are differences in the GWP of 1 kWh of thermal power between provinces and national average. Eighteen provinces have higher GWP comparing with the national average. (3) There are differences in the life cycle GWP of hybrid power between different provinces. Inner Mongolia and Qinghai have the largest and the smallest GWP for 1 kWh of hybrid electricity supply, respectively. We also analyzed GWP map caused by total power generation in China. This life cycle inventory of different types of power in provinces can provide technical support for power supply management, energy conservation, and emission reduction at both provincial and state levels. The inventory also provides a basic database for LCAs of materials, products, and industries.

1. Introduction

The electric power industry is a key component of the national economy and of social development, serving as the main supplier of energy. China is a rapidly developing country. The consumption of electricity in China has increased, with 76% growth in the period from 2006 to 2013 (Fig. 1). In 2013, China's total power production was 5372.1 billion kWh, of which 78.6% and 16.6% were thermal power and hydropower, respectively (NBOS, 2013). The main source of power supply in China is thermal power; other sources account for 22% of total production, but this share is increasing.

The significant amount of fossil fuel-based power production, especially of coal-based power, renders the industry highly energy intensive and polluting (Liu et al., 2015). In 2013, sulfur dioxide and dust emissions from the power industry contributed 42% and 19%, respectively, of total national emissions (National Bureau of Statistics, 2013); this has led to pressure for stronger environmental protection. Many studies have pointed to the significant potential of other power sources, such as wind power, solar power, and hydropower, to enable energy savings and emission reductions (Asdrubali et al., 2015; Hong et al., 2015). These renewable energy sources are now recognized as central to sustainable development (Cucchiella et al., 2015).

As shown in Fig. 2, there are large differences in the types of power and capacities for power generation among different provinces in China. Jiangsu province is the largest producer of electricity in the country, with 415.8 billion kWh generated in 2013; thermal power accounted for 95% of that amount. In Sichuan province, total generation is of 212.9 billion kWh, of which 73% is provided by hydropower. Guangdong is the largest producer of nuclear power, with this source contributing 13% of total power. Wind power contributes 9% of total power in Inner Mongolia, with this province being the largest producer of wind power nationally. It is therefore very important to create environmental profiles of power taking into consideration these differing situations in different provinces of China.

Life cycle assessment (LCA) methodology has been widely applied to evaluate the environment performance of electricity

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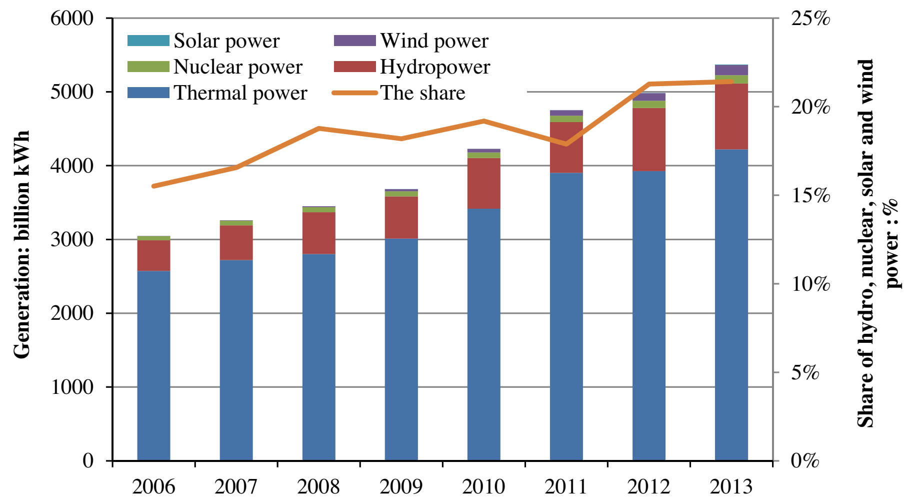

Fig. 1. The power generation and the share of hydro, nuclear, solar and wind power in China.

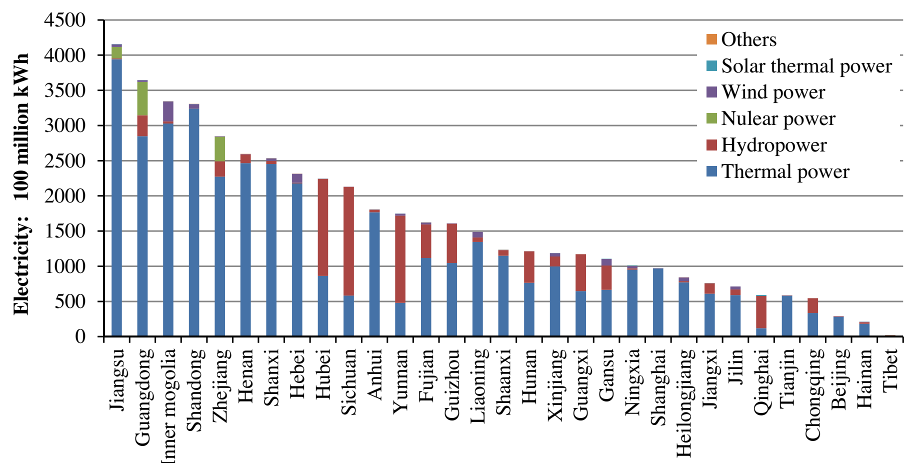

Fig. 2. The production and share of different power supplies in provinces.

(Hertwich et al., 2015; Singh et al., 2015). Some researchers have carried out LCA for domestic electricity supply, such as in Britain, Australia, Poland and Denmark (Adamczyk and Dzikuc, 2014; Hardisty et al., 2012; Stamford and Azapagic, 2012; Turconi et al., 2014). These studies focused on the environmental impact of power industries within these countries, providing a basis for energy conservation and emission reductions in the electric power industry. A significant number of studies have focused on one type of power source, such as solar power, hydropower, or nuclear power, highlighting the advantages for environmental impact of using clean energy (Cambero et al., 2015; Kim et al., 2012; Nian, 2015; Singh et al., 2015; Varun et al., 2012). These studies also provide insights for revising power structures.

In recent years, there have been studies about LCA of electricity at national level in China, with these including almost all main types of power generation sources, such as thermal power (Di et al., 2007), solar PV (Fu et al., 2015; Yang et al., 2015b), wind power (Xue et al., 2015; Yang et al., 2015a), nuclear power (Jiang et al., 2015; Ma et al., 2001), and hydropower (Hu et al., 2013; Pang et al., 2015). These studies measured energy consumption and pollutant emissions per unit power generation. Qu et al. focused on specific elements of different power types for comparative purposes, including thermal power, hydropower, and nuclear power (Ou et al., 2011).

The studies about LCA of thermal power have mainly assessed the life cycle of fuel supply. The LCA of solar power have focused primarily on the production of solar PV. Yang et al. conducted the LCA of PV modules, taking into account six life cycle stages and providing detailed input data; however, their assessment was not extended to consider electricity produced. In the case of hydropower, most studies have focused on infrastructure construction and station operation. Hu et al. considered almost all stages of construction (such as excavation, filling, transportation, and operation), providing input data for each stage (Hu et al., 2013). In one paper of LCA of nuclear power, Jiang et al. calculated the carbon emissions of nuclear power, including construction of facilities, mining and processing of uranium, and station operation, based on investigation of a uranium plant (Jiang et al., 2015). LCA of wind power have focused on the production of equipment for wind power generation.

These China-focused studies have focused on single power generation methods or parts thereof, and all were carried out at national level. There is consequently still an absence of integrated and comparative LCAs for multiple electricity pathways, based on provincial level. There is therefore a shortage of LCA data for provincial power systems and their environment impact thus remains unclear. In our study, we developed an LCA model for supply of thermal, wind, hydro, nuclear, and solar power in various provinces in China. We further compiled a provincial life cycle inventory (LCI) and a national LCI based on provincial data. The results in our paper can, not only provide data to support energy management, energy