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The striking amount of carbon emissions by the construction stage of coal-fired power generation system in China

X.D. Wu, J.L. Guo, G.Q. Chen*

College of Engineering, Peking University, Beijing 100871, China

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ABSTRACT

Based on an extensive review of related studies, the striking amount of carbon emissions induced by the construction stage of a typical 2 × 660 MW coal-fired power generation system is revealed, by means of systems LCA as a concrete hybrid of process analysis and input-output analysis. Differing from previous works that simply treat the whole inputs in the construction stage as some primary materials, this study inclusively covers all input items as products of the economy, supported by input-output database. An integrated inventory that contains over seventy items is established, in which the materials, equipment, and services inputs throughout the construction stage are given full consideration. In magnitude, the greenhouse gas emissions embodied in the construction stage of the power plant are calculated in carbon dioxide equivalent as 1.54% of those from coal combustion, which are several times or even one order of magnitude higher than that estimated in some previous studies. The emissions induced by coal-fired power generation infrastructure in China are accordingly estimated, in magnitude up to 0.6%, one-eighth and one-sixth of the total national emissions in China, UK and France, respectively. The outcome provides a unique perspective for policy makers into apprehending carbon emissions by the power sector.

1. Introduction

Coal-fired power plants play a leading role in securing reliable electricity delivery, which account for over 40% of the worldwide annual electricity production in 2014 (IEA, 2016). The associated carbon emissions (namely greenhouse gas emissions) have thus remained a critical concern in the battle against climate change. In EIA (Energy Information Administration) scenario, global energy-related CO_2 emissions have recorded a new level of 32310 million metric tons in 2012 and over one fifth of the emissions come from thermal power generation (EIA, 2015).

Especially, for China as the largest electricity producer and consumer in the world, whose electricity production has risen from 1008 TWh in 1995 to 5650 TWh in 2014 (NBS, 2016), coal-fired power plants hold responsible for over 70% of the total electricity production. The associated CO_2 emissions from coal combustion, have occupied over 40% of the total carbon emissions in China (Wu et al., 2016b). As a result, mitigating carbon emissions from coal-fired power plants has been listed as a top priority by the Chinese government, for the purpose of fulfilling its commitment of peaking the carbon emissions by the end of 2030 in the Paris Agreement (Tollefson, 2016). In particular, in China's 2015 government report presented to the National People Congress, it is pointed out that CO_2 emission intensity is to be slashed by at least 3.1% in the coming year, and coal-fired power plants are to receive ultra-low-emission retrofitting to lower the coal-consumption rate (Li, 2015). Generally, the relevant governmental policy packages give consideration to the onsite carbon emissions of coal-fired power plants only, while the emissions taking place in the upstream processes are generally neglected.

Extensive academic efforts have been taken to investigate the carbon footprint of coal-fired power generation systems, namely the carbon emissions emitted directly and indirectly along the life cycle of coal-fired power plants (Chang et al., 2015; Feng et al., 2014; Pehnt and Henkel, 2009; Petrescu et al., 2017). For instance, Chang et al. (2015) estimated the carbon footprint of four types of coal-fired power generation systems in China by giving full consideration to the emissions induced by fuel extraction, fuel transportation and power generation. While these life cycle accountings are quite valuable in supporting our understanding on emissions by different stages of coal-fired power plants, emissions induced by the construction stage (namely those induced by power plant infrastructure) are generally neglected. Actually, the economic growth in China during the last several decades is largely driven by the massive investment (Fu et al., 2014). The consequence is that fixed capital formation (mainly infrastructure such as railways,

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* Correspondence to: Laboratory of Systems Ecology, College of Engineering, Peking University, Beijing 100871, PR China.
E-mail address: gqchen@pku.edu.cn (G.Q. Chen).

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airports, plants and industrial facilities) accounts for the majority of the emissions or energy use induced by domestic final demand, as demonstrated in some existing studies (Chen and Wu, 2017; Chen and Zhang, 2010).

Since coal-fired power plants are of paramount importance for electricity delivery in China, they constitute an important component of the domestic infrastructure. According to China Electricity Council (CEC, 2011), in 2011 alone, an amount of around 98 billion CNY is invested for thermal power plant infrastructure, which shares around one-tenth of the total capital inputs into the secondary industries in China. Hence, though the carbon emissions induced by construction of a coal-fired power plant may be much smaller than those from coal combustion, the aggregated carbon footprint by domestic coal-fired power plant infrastructure could reach a striking amount. In addition, in recent years a small number of coal-fired power plants have been equipped with carbon capture facilities (Wu et al., 2016b; Zheng et al., 2011). For these carbon capture power plants, since the majority of the carbon emissions coming from fuel combustion are captured, the emissions induced in the construction stage may appear to be considerable compared to the onsite emissions directly discharged, as having already been observed in some existing works (Ruether et al., 2004). Besides, the remarkable amount of carbon emissions induced by plant construction has been widely demonstrated for renewable power alternatives, such as solar power and wind power (Chen et al., 2011c; Klein and Rubin, 2013). For instance, supported by an inventory of life cycle inputs including the related materials, equipment and services, Chen et al. (2011d) revealed that the construction stage accounts for around 80% of the lifetime carbon emissions of a 1.5 MW solar power tower plant.

However, for coal-fired power plants, insufficient attention has been paid to the carbon emissions induced by plant construction. In some studies (Gorokhov et al., 2002; Odeh and Cockerill, 2008a, 2008b), though the construction stage is considered, the associated carbon emissions are mostly treated as the greenhouse gas emitted to produce some primary materials for the preparation of some inputs and/or as some other inputs themselves to the construction. A process-based LCA (life cycle assessment) as a bottom-up method is commonly applied. The plant infrastructure is traced back to the chain of inputs, and inputs are traced back to the sub-inputs. For instance, Liang et al. (2013) investigated the life cycle carbon emissions of four clean coal power generation technologies in China by treating the inputs in the construction stage as some primary materials. The carbon footprints of plant infrastructure are respectively estimated to be 0.66 g CO_2-eq/kWh (for integrated gas combined cycle system), 1.29 g CO_2-eq/kWh (for subcritical coal power generation system), 1.01 g CO_2-eq/kWh (for supercritical coal power generation system) and 0.88 g CO_2-eq/kWh (for ultra-supercritical coal power generation system). Similar studies have been undertaken by Spath et al. (1999), Gorokhov et al. (2002), Odeh and Cockerill (2008a) and Hondo (2005) to investigate the life cycle carbon emissions of coal-fired power plants in other nations. Nevertheless, the process analysis may suffer from truncation errors and the uncertainty brought about by subjective definitions of systems boundary (Hendrickson et al., 1998; Joshi, 1999; Suh, 2009; Wiedmann and Minx, 2008).

As a result, the input-output analysis has been adopted in some studies since it may effectively offset the truncation errors inherent to process analysis (Crawford et al., 2018; Wiedmann, 2009; Williams et al., 2009). For instance, Proops et al. (1996) applied input-output analysis to exploring the lifetime carbon emissions of several types of coal-fired power plants in the United Kingdom and calculated the total carbon effect associated with construction of the plants. Nevertheless, the input-output model generally gives an average resolution of each economic sector because of the high aggregation of data, which increases the difficulty and uncertainty to analyze a specific (or atypical) product or technology (Bullard and Pilati, 1976; Suh and Huppes, 2005). Hence, Ruether et al. (2004) moved a further step to present an input-output-based LCA for carbon emissions associated with construction of coal gasification power generation plants in the United States and compared the result with that obtained by process-based LCA, revealing that the associated carbon emissions are greatly underestimated by process-based LCA. This study is quite valuable in that it has for the first time established a detailed cost budget for plant construction. Moreover, supported by carbon emission intensities obtained from input-output analysis, the carbon emissions associated with each input item are quantified. Nevertheless, such analysis based on detailed inventory for construction of coal-fired power plants in China is still lacking.

In this paper, based on a comprehensive inventory (over seventy input items) through the construction stage of a most typical 2 × 660 MW coal-fired power plant in China, we seek to fill the blanks in previous studies by accounting for the associated carbon emissions (including CO_2, CH_4 and N_2O emissions). A systems LCA method is adopted, supported by process analysis and carbon emission intensities obtained from systems input-output analysis. The remainder of this paper is organized as follows: Method and data sources are respectively enunciated in Section 2 and Section 3; Section 4 presents the results and illustrates the contributions of related industries to the whole carbon emissions; Comparisons are made in Section 5; Conclusions and policy implications are formulated in the final section.

2. Method

In the 1970s, Bullard et al. (1978) proposed a hybrid method that combines process analysis and energy intensity coefficients obtained from energy input-output analysis to calculate the energy required directly and indirectly to produce different kinds of goods or services. The process analysis as a bottom up method is appreciated for providing detailed process information into the input items of a product or technology. Then, by means of energy input-output analysis, which has been proposed and widely used in the 1970s by the energy research group in University of Illinois to assess energy costs of goods (Bullard and Herendeen, 1975a, 1975b; Herendeen, 1973), embodied energy intensity coefficients that represent the total energy requirements of each input item (and the corresponding economic sector) could be calculated. It is especially worth noting that this energy input-output analysis that is based on the sectoral balance of embodied energy flow differs from environmental-extended input-output analysis (EEIOA) in that the corresponding intensity applies to all sectoral output while the EEIOA intensity is applicable only to final use, not to intermediate inputs (Herendeen, 1973).

Originated from the energy balance model raised by Herendeen (1973) and the thought of systems ecology by Odum (1983), Chen and his colleagues moved further to generalize the energy input-output analysis to systems input-output analysis for embodiment accounting of ecological element, such as energy use (Chen and Wu, 2017; Chen and Chen, 2011b), land use (Chen and Han, 2015; Han and Chen, 2018), carbon emissions (Chen and Zhang, 2010; Chen and Chen, 2011a), mercury emissions (Chen et al., 2016). A systems LCA method was then suggested as a combination of process analysis and the embodied intensity generated from systems input-output analysis. This has been widely applied to accounting of energy use (Wu and Chen, 2017; Wu et al., 2016a), water use (Meng et al., 2014; Shao and Chen, 2013), and carbon emissions (Chen et al., 2011a, 2011b) of various industrial facilities (such as power generation plants, wastewater treatment plants, wetlands, and buildings). By choosing a suitable boundary, the process analysis allows us to trace the chain of inputs to the level where all the inputs are well covered in typical industrial sectors as categorized in the macro-economy statistics, thus minimizing the errors triggered by the high aggregation. Then, by resorting to systems input-output analysis, the carbon emissions embodied in per unit monetary output of each economic sector could be estimated, thus properly avoiding the truncation errors associated with process analysis by guaranteeing the