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Using forest area for carbon footprint analysis of typical steel enterprises in China

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ABSTRACT

Steel industry is an important mainstay industry and key greenhouse gas emitter of China. Employing life cycle assessment method of cradle-to-gate and establishing material flow model for steel production processes, this paper analyzed carbon footprints of steel enterprises to reduce carbon emission efficiently. Taking the function of forest to capture carbon into account, carbon footprint was expressed as the forest area instead of carbon dioxide equivalent (CO_2e). Taking five typical steel enterprises (J, A, T, N, B) in China as examples, the carbon footprint per ton of steel in each process was calculated and its influence factors were analyzed. Results show that (1) from the perspective of process, the carbon footprint of iron-making, in which a large amount of coke and coal is consumed, is the largest, followed by the process of coking and sintering; (2) analyzing the type of gas, CO_2 contributes over 70% of the total carbon footprint in the whole production process; (3) the average carbon footprint per ton of steel was 0.325 hm^2/t. Among five companies, carbon footprints of company N were up to 0.342 hm^2/t, while company B had the lowest carbon footprint, at only 0.291 hm2/t. The gaps of carbon footprint are mainly due to geographical differences, energy consumption construction and product equipment and technology. The carbon footprint of enterprises was compared with the local carbon capacity, and analysis results show that the steel output and local forest areas could be significant factors determining whether the carbon emissions discharged by steel mills exceed the local carbon capacity and cause environment problems. According to analysis results, corresponding opinions and policies were proposed.

1. Introduction

Global warming is becoming an increasing serious environment problem that human beings faced, thus causing great pressure for reduction of CO_2 emissions. As the biggest CO_2 emitter all over the world and contributing almost one-third of the total emissions in 2013 (Lin et al., 2016), China has become the focus of global effects to reduce CO_2 emissions. The Chinese government has raised the target of reducing CO_2 emissions per unit of GDP by 40%-45% compared to 2005 by 2020 and made a pledge of more recent 2030 Greenhouse Gas (GHG) cap commitment under the joint climate statement with the U.S. on November 11, 2014 (Liu and Gao, 2016). Due to the great energy consumption, the industrial sector has become a major source of CO_2 emissions (Hong-min, 2009; Huang et al., 2017; Yue et al., 2015). Therefore, it is significant to investigate the key factors influencing the CO_2 emissions in major industries.

China is currently the world's largest steel production and consumption country (Xu and Lin, 2016), representing almost 50% of the global steel output. However, great energy consumption and CO_2 emissions are paid as the price for the increasing steel production. In 2013, the iron and steel industry consumed 625 million tons of standard coal equivalent (tce) and produced 1687 million tons of CO_2, accounting for 16.2% of China 's total emissions (Xu and Lin, 2017; Yang et al., 2016), and ranked as the third largest industrial CO_2 emitter in China after the power sector and cement sector (Huang et al., 2010; Zeng et al., 2009). The low carbon development of iron and steel industry, which possesses huge carbon reduction potential, is highly necessary for meeting the country's CO_2 emission reduction targets (Porzio et al., 2013; Tian et al., 2013; Wang et al., 2007; Yue et al., 2015). Although most researchers focus on CO_2 emissions from power plant and cement production (Abdul Manaf et al., 2016; Chen et al., 2017; Galvez-Martos and Schoenberger, 2014; Saade et al., 2015), the emissions from iron and steel industry is not well studied. Therefore, identifying the main factors affecting the CO_2 emissions of steel industry would help policymakers formulate affective emissions reduction policies and achieve China's emission reduction targets.

Several previous studies have compared steel enterprises from different countries (Gao et al., 2015b; Tanaka, 2012; van Ruijven et al.,

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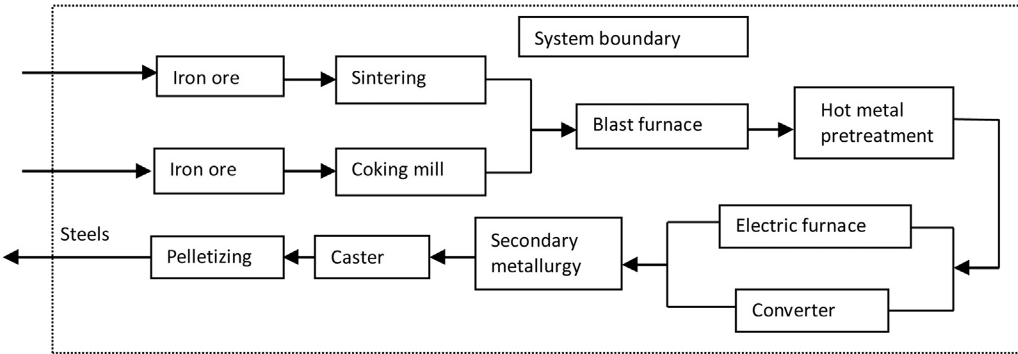

Fig. 1. Schematic of the steel enterprises' carbon footprint within the system boundary.
Notes: In this figure, production processes are shown in square boxes; full single-headed arrows denote flow direction of Fe mass across/within the system boundary. The boundary begins with iron ore input, ends with steel products output, undergoing the process of sintering, coking, blast furnace and so on.

2016) and regions (Xu and Lin, 2016) to find solutions to reduce the carbon emissions of steel industry. In addition, other studies have analyzed carbon emissions potentials in varies of models, in which different policies and technology strategies are employed and tried to identify a relatively better development model (Hasanbeigi et al., 2013; Lee, 2013; Wen et al., 2014). In recent years, to better understand the sources of carbon emissions produced, some researchers and enterprises have done many works concerning the emission trajectory, features and driving forces in the steel production process (Tian et al., 2013; Wang et al., 2013b); moreover, impacts of material flows and energy flows on carbon emissions have been analyzed to forecast the accurate carbon reduction potentials (Cai et al., 2008; Dai, 2015; Gao et al., 2015a). Only limited studies have been performed on the environmental impacts of steel industry (Morrow Iii et al., 2014; Zhang et al., 2012). As a comprehensive indicator, the term "carbon footprint" (CF) has been widely used to assess the environmental impacts of various enterprises or activities. Employing tiered hybrid life cycle assessment (LCA) method, some scholars calculated carbon footprints of an industrial park in China and a reflective foil of an Italian company respectively and the main sources of carbon footprints were determined (Turner et al., 2015; Xuan and Yue, 2016). Several studies decomposed CF of national parks in the U.S. and refrigeration systems into two forces-direct emissions of various GHG and leakage, and indirect emissions of CO_2 equivalent (CO_2e) due to energy consumption (Villalba et al., 2013; Wu et al., 2013). In their studies, values for CF are in CO_2e, which could not provide sufficient information about the environment load caused by carbon emissions. Besides that, for steel industry, few studies have focused on carbon footprint of steel enterprises (Sodsai and Rachdawong, 2012; Wang et al., 2013a).

In this paper, employing the LCA method of cradle- to-gate, we calculated carbon footprints of five typical steel enterprises in China through establishing material flow models for steel production processes. Then, carbon footprints of these steel enterprises were compared with local carbon capacity, and the key factors influencing carbon footprints were identified. Aiming to in keeping with ecological footprint, we characterized carbon footprints by the ecological land required to capture GHG discharged instead of CO_2e, which could provide a clear and specific impression of environment load caused by carbon emissions through comparing it with the local carbon capacity. In most studies, the carbon capacity usually is expressed as forest area. In addition, the concept of carbon deficit was employed to indicate the state that carbon emissions exceed the carbon capacity of local province and cause environment problems. These provinces in carbon deficit could be the focus of CO_2 reduction.

2. Methods

The steel production processes are open, irreversible, and complex iron-coal systems far away from balance. Specially, they are not only material production processes in which raw materials containing element Fe are converted to steel products or scraps undergoing a series of physical and chemical changes, but also energy conversion processes in which energy is converted to energy products or emissions undergoing several inks of processing, conversion, modification.

2.1. Determination of the boundary

The life cycle of the iron and steel industry includes raw material extraction (mainly iron ore and coal), iron and steel production process, product consumption, recycling, and transportation process. The consumption of iron and steel products varies dramatically depending on the end use (e.g. buildings, pipes, automobiles, and appliances), thus, the LCA method of cradle-to-gate was applied in this study. Many studies have also used this method (An and Xue, 2017; Chan et al., 2015). In addition, because the production mills and iron ores and coals are usually located in the same region, transportation was not included in the scope of this study. Moreover, according to the reference (The Editorial Board of China steel yearbook, 2016), the electricity consumed for open mining and underground mining is 0.88 kWh/t and 11.20 kWh/t respectively, and the diesel consumed for open mining is 0.25 kg/t. The carbon footprint associated with mining are too small to be ignored. The production processes are utilized as the main body, which is the most important part that manufacturers should consider in industrial carbon footprint assessments. Thus, we focus on the carbon footprint assessment in the production process of steel enterprises.

Direct energy consumption CF, outsourcing electricity CF and auxiliary raw materials CF, generally covering almost all carbon footprints discharged in steel production processes, were calculated and key factors of reducing carbon emissions were identified. According to this, the system boundary was determined. As seen in Fig. 1, the boundary begins with iron ore input, ends with steel products output, undergoing the process of sintering, coking, blast furnace and so on.

2.2. Establishment of model

On the basis of understanding the structure and functioning of the industrial metabolism, and utilizing material flow analysis (MFA) as a tool to follow and quantify the flow of carbon, we identified the GHG production and inputs and outputs in the steel production process. As seen in Fig. 2, in the steel production process, putting in fuels (coal, oil, and electric), raw materials (ore and waste steel), air and water, undergoing several energy conversion and material production processes, one segment of these natural resources is converted into products (various types of steel), another part is changed into energy and material returns, and the remainder produces pollutants or abandoned products, which are discharged into the environment, producing carbon footprint from each link and flow and eventually leaving the system as pollutants or waste.

2.3. Analytic procedure

In each process, since all kinds of substances and elements were