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Comparison of greenhouse gas emission accounting methods for steel production in China

Ran Jing, Jack C.P. Cheng*, Vincent J.L. Gan, Kok Sin Woon, Irene M.C. Lo

Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology, Hong Kong, China

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ABSTRACT

Steel production is an environmentally sensitive process accounting for 10% of greenhouse gas (GHG) emissions in China, which represents 4–5% of the world's total anthropogenic GHG emissions. This study presents and compares three GHG emissions accounting methods for steel production in China, which are the Intergovernmental Panel on Climate Change (IPCC) method, the Life Cycle Inventory Localization (LCIL) method, and the Comprehensive Energy Consumption (CEC) method. Different criteria such as sources of data, energy input-based and process-based analyses, and benefits and limitations of the three methods are compared and discussed. On the basis of the data collected and system boundary defined in this study, the total GHG emissions of the IPCC, LCIL, and CEC methods are estimated as 1.717, 1.715, and 1.959 kg CO_2-e/kg steel, respectively. The results of the IPCC and CEC methods show that the coal and coke combustion contributes 90.2% and 84.5% of total energy related GHG emissions during steel production in China, respectively. For the LCIL method, it quantifies the GHG emissions from each individual sub-processes associated with the sintering process to the electric arc furnace process. The results of the LCIL method indicate that the hotspot area for GHG emissions during steel production is the blast furnace process, which accounts for 78.4% of the total energy related GHG emissions. These three methods can be applied to other countries to investigate their GHG emissions. Moreover, the comparison of these three methods provides insights for adopting appropriate methods to calculate GHG emissions for steel production.

1. Introduction

In 2012, the world's steel production was 1545.01 million tonnes (WSA, 2013a). China produced 716.54 million tonnes of steel (WSA, 2013b) and it accounted for 3-4 percent of China's GDP in 2012 (Stanway and Lian, 2012). The steel production in China increased by 3.1 percent in 2012 due to the economic growth and demand for road and railway constructions (Asian metallurgy, 2013). According to the Chinese Statistics Bureau, it's the 31st annual increase in steel production and came as the world's second-largest economy expanded 7.8 percent in 2012 (Asian metallurgy, 2013). Steel production is a high energy intensive industry with large emissions of greenhouse gas (GHG) (Burchart-Korol, 2013). According to Tian et al. (2013), steel production accounts for approximately 4–5% of the world's total GHG emissions. In China, steel production is the third largest GHG emissions sector accounting for 10% of total GHG emissions (Zeng et al., 2009). Estimation and assessment methods for GHG emissions from steel production have been developed in China (Price et al., 2002; Wang et al., 2007; Shangguan et al., 2010). Shangguan et al. (2010) calculated the CO_2 emissions from steel production in China based on the analysis of carbonaceous flow, in which the CO_2 emissions from energy consumption in the steel industry in China accounted for over 90% of the total CO_2 emissions. Price et al. (2002) examined the CO_2 emissions from the steel industry by modifying the official Chinese energy consumption statistics for steel production in China in order to avoid double-counting of certain data such as the coal-based energy consumption. Price et al. (2002) found that the energy use and CO_2 emissions associated with steel production in China were higher than those in Brazil, India, Mexico and South Africa. Wang et al. (2007) investigated the energy consumption and CO_2 emissions from steel industry in China through the generation of three different scenarios using the Long-range Energy Alternative Planning (LEAP) software. These studies applied different GHG accounting methods and various data from literature and carbon emission factors for China in the calculation of CO_2 emissions, rendering different outcomes

* Corresponding author. Tel.: +852 23588186; fax: +852 23581534.
E-mail address: cejcheng@ust.hk (J.C.P. Cheng).

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for the CO_2 emissions from steel production in China. The objective of this paper is to investigate the three different methods in GHG emissions accounting by comparing three methods for calculation of the GHG emissions from steel production in China based on GHG emission factors for China and various expressions of energy consumption data (e.g., consumption of fuel or electricity, embodied energy consumed in the intermediate steel manufacturing process, comprehensive energy consumption).

In this study, the first method follows the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). The GHG emission factors and the energy consumption data from existing steel plants in China are applied to the IPCC method. The second method is the localization of the Ecoinvent database. In this method, the GHG emissions of each individual sub-process of steel production related to energy are calculated based on the embodied energy GHG emission factors for each type of energy used (i.e., coal, coke, electricity, and natural gas). In the third method, the GHG emissions of steel production in China are calculated in reference to comprehensive energy consumption (CEC), the percentage distribution of primary energy used for steel production in China, and the GHG emission factors for stationary combustion for each type of GHG. The results of GHG emissions, data inputs and sources, differences, benefits, and limitations of each method will be discussed.

2. Methodology

2.1. Modeling scope of study and description of steel manufacturing process in China

In this study, the system boundary is "Gate-to-Gate", which covers the manufacturing process from raw materials (factory-entry gate) to the final product (factory-exit gate). The most important assumption in an application of the life cycle inventory localization (LCIL method) is that Mainland China should have similar steel manufacturing processes as described in the life cycle inventory used in this study. Therefore, the typical steel manufacturing process in Mainland China needs to be identified. A typical steel manufacturing process in the Mainland China consists of a blast furnace (BF) process, a basic oxygen furnace (BOF) process and an electric arc furnace (EAF) process. Fig. 1 shows the process flow diagram of steel production in China. Firstly, the raw materials (e.g., iron ore, coal, coke and limestone) are fed into the BF, followed by air injection to the furnace through the openings at the bottom of the shaft above the hearth crucible. With the presence of air, the coke burns along with the injected fuels, such as tar or light oil, to produce the necessary heat and generate reducing gas to remove oxygen from the ore in the reduction process. After the BF process, a portion of the pig iron is sent to the BOF. High purity oxygen is blown through the molten bath of iron in the BOF to reduce the concentration of carbon, silicon, manganese, and phosphorous in pig iron, while various fluxes (i.e., burnt lime or dolomite) are used to reduce the levels of sulfur and phosphorous. The remaining pig iron is sent to the EAF which relies on recycled steel scrap as raw material. Recycled steel scrap is melted and refined using electrical energy imparted to the charge through carbon electrodes and then alloyed to produce the desired grade of steel.

In this study, the total GHG emissions are divided into two parts: (1) energy related GHG emissions, which consist of the GHG emissions from the fuel combustion and electricity consumption; (2) non-energy related GHG emissions, which mainly encompass the chemical reactions during the steel production process. The results of the GHG emissions are expressed in terms of carbon dioxide equivalent (CO_2-e), with global warming potential (GWP) values over a 100-year time horizon (IPCC, 2007). The GHG

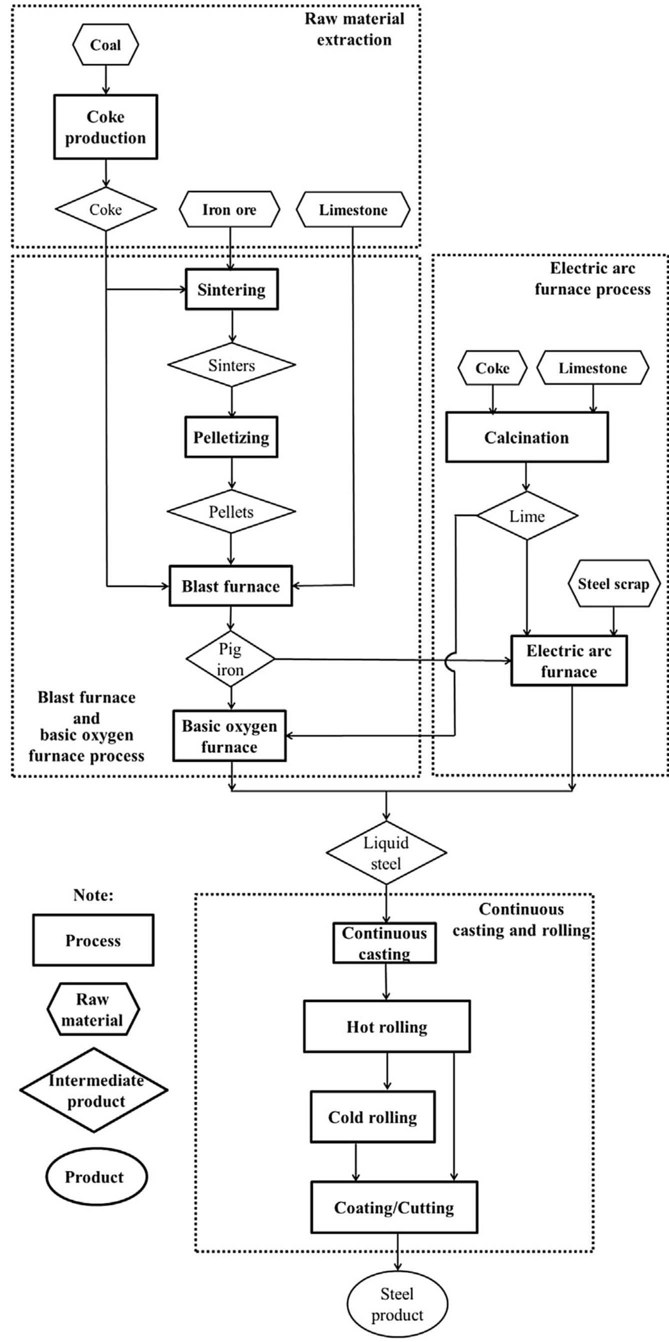

Fig. 1. Process flow diagram of steel production in China.

emission factors used in this study are obtained from the GHG Protocol Tool for Energy Consumption in China in 2011 (WRI, 2013). The GWP values of CO_2, CH_4 from fossil sources, and N_2O are 1, 25, and 298, respectively (IPCC, 2007). The descriptions of the methodological approach and equations used for each method are explained in Section 2.2, 2.3, and 2.4.

2.2. Calculation of GHG emissions using the Intergovernmental Panel on Climate Change guidelines for national greenhouse gas inventories (IPCC method)

The GHG emissions from each type of energy are calculated using the Tier 2 method IPCC, with a multiplicative product of the