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Analysis of life-cycle GHG emissions for iron ore mining and processing in China—Uncertainty and trends

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ABSTRACT

Total iron ore demand in China grew to 1.1 billion tonnes in 2013 as a result of ongoing urbanization and massive infrastructure development. Iron ore and steel production are major sources for greenhouse gas (GHG) emissions. Since China has committed to lowering carbon intensity to meet climate change mitigation goals, detailed studies of the energy use and GHG emissions associated with iron ore mining and processing can aid in quantifying the impact and effectiveness of emissions reduction strategies. In this study, a life-cycle model for mining and processing of Chinese iron ores is developed and used to estimate GHG emissions. Results show that the mean life-cycle GHG emissions for Chinese iron ore production are 270 kg CO_2e/tonne, with a 90% confidence interval ranging from 210 to 380 kg CO_2e/tonne. The two largest contributors to overall GHG emissions are agglomeration (60%) and ore processing (23%). Iron content (ore grade) varies from 15% to 60% and is the largest contributor (40%) to the uncertainty of the results. Iron ore demand growth and the depletion of rich ore deposits will result in increased exploitation of lower grade ores with the concomitant increase in energy consumption and GHG emissions.

1. Introduction

China's urbanization and its associated massive infrastructure development are creating rising demand for iron ore and steel production (Shen et al., 2005). Total iron ore demand grew from 200 million tonnes in 2001 to 1.1 billion tonnes in 2013. With all grades converted to 62% Fe iron content, the rise in ore use is equivalent to an average yearly increase of 15% (China Steel Yearbook, 2014). China is the world's largest iron ore producer and consumer, responsible for 45% of total global production and 55% of total consumption (U.S. Geological Survey website). This consumptive growth leads to the depletion of iron-ore resources and increased exploitation of lower quality ores (China Steel Yearbook, 2014). Produced, crude ore grade has dropped from 30% Fe to 27% Fe between 2006 and 2012 (China Steel Yearbook, 2014). Processing lower grade ores for an equivalent mass of ore concentrate requires higher energy intensity, potentially resulting in increased GHG emissions (Norgate and Haque, 2010).

As the largest GHG emitter (Friedlingstein et al., 2014), China committed to lowering the carbon intensity of its economy by 60% to 65% from the 2005 level by 2030 (Karali et al., 2014). To meet this commitment, China needs to develop a multitude of GHG emissions reduction strategies. The iron and steel sector could be a major focus, as it contributes about 12% of the country's total GHG.

In addition to direct GHG emissions within the iron ore sector, iron ore production can lead to indirect emissions from other sectors that supply required goods and services, such as raw material, energy production, and transportation. This study uses life-cycle assessment (LCA), which traces the product impacts under study (in this case, iron ore), and includes impacts from relevant upstream and downstream processes (cradle to gate). LCA is a widely used method of researchers and policymakers for decision making (Scott Matthews et al., 2014).

Studies have determined China's iron and steel sector emissions using a variety of approaches (Karali et al., 2014; Li et al., 2016; Chen et al., 2014; Hasanbeigi et al., 2013), but these studies either did not model the upstream emissions for iron production and processing, as the objective of the work was to determine the size of the sectorial emissions or to explore mitigation possibilities. Li et al. did include upstream ore mining and processing but aggregated the results for coal and iron ore production (Li et al., 2002; Iosif et al., 2008). Stewart (2001) suggest mining data availability, data quality, and representativeness as the primary reasons there are few LCA studies for minerals mining in general.

Two LCA studies estimate the GHG emissions of iron ore mining and processing in Australia and Brazil (Norgate and Haque, 2010; Ferreira et al., 2015). Norgate and Haque estimated Australian iron ore mining and ore processing GHG emissions at 12 kg CO_2e/tonne (Norgate and

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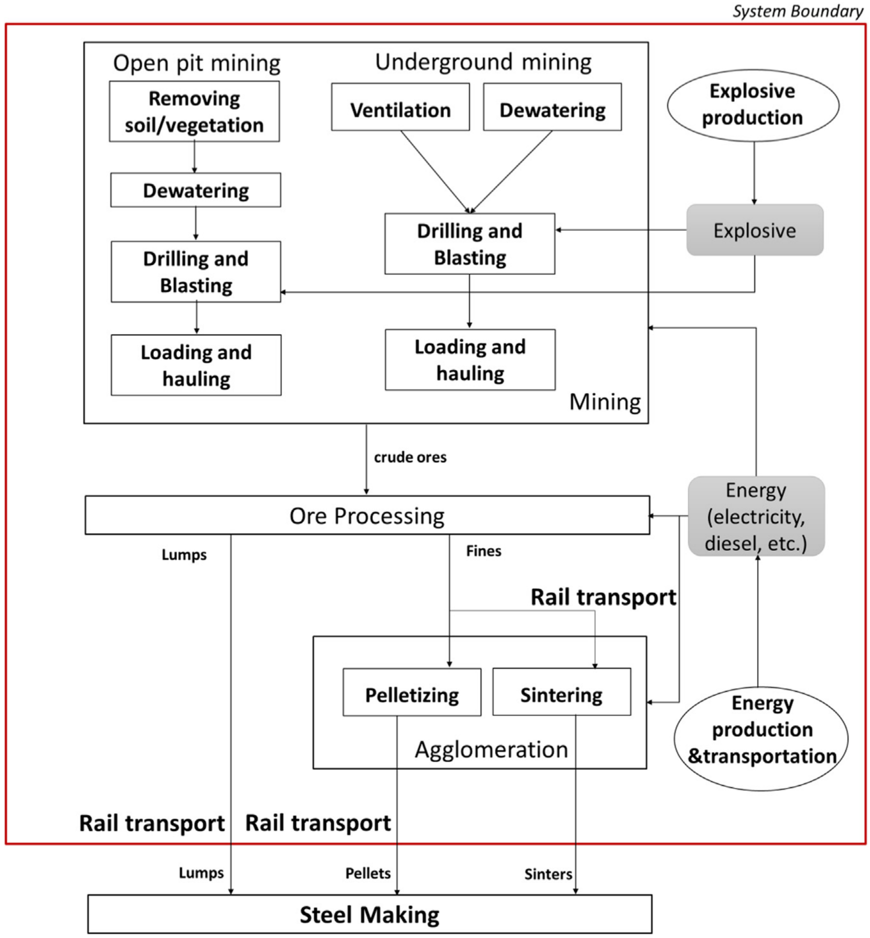

Fig. 1. Chinese iron ore mining flowsheet and the associated LCA system boundary. Rectangular boxes indicate unit operations of iron mining and processing; Shaded boxes indicate energy and explosives input; Rounded boxes indicate upstream processes of energy and explosives production.

Haque, 2010). Ferreira et al. (2015) reported Brazilian these emissions as 13 kg CO_2e/tonne. With general uncertainty related to data and LCA methods these results should be considered the same (Scott Matthews et al., 2014).

The GHG emissions estimates can slightly due to geological and operating conditions (Ferreira et al., 2015) and there are substantial differences in Chinese ore mining compared to these studies, such as greater average mine depth and lower grade ore extraction. These attributes are expected to change the China's emissions estimate (China Steel Yearbook, 2014).

This study develops a life-cycle model to determine the GHG emissions of iron ore mining and processing in China. By using data from varied sources and at different levels of aggregation, the study provides average sectoral estimates, and uncertainty ranges for the life-cycle inventory (LCI) results. Sensitivity analysis is used to determine the parameters that drive model results and highlight future data needs and areas requiring further study. Based on the results, the study further discusses viable ways of GHG emissions reduction and provide utility for policy makers.

2. Methods

The following presents data and methods used for estimating GHG emissions from Chinese iron ore production. The emissions embodied in three forms of iron products (lumps, sinters, and pellets; defined below) are analyzed. This analysis includes GHG emissions throughout the mining and ore processing stages, as well as indirect emissions associated with the consumption of energy and explosives during the mining and concentrating processes.

2.1. Goal, scope, system boundary, and functional unit

The goal of the study is to determine the GHG emissions of Chinese iron ore mining. The iron ore production system and the system boundary used are shown in Fig. 1 and include mining, ore processing, and agglomeration stages.

Open pit and underground mining are modeled. The functional unit is one metric ton of processed iron-ore delivered to the blast furnace, the entry point to the steel making process. The blast furnace requires ore with an Fe content of 60% or higher. Lumps, sinters or pellets are all used as feedstock. These three forms of iron ore are treated as equivalent in this study as they all are sized to between 10 and 30 mm, and have an iron content of 60% or higher.

The final results are presented in terms of 100-year global warming potentials (GWPs), using GWP factors reported by the Intergovernmental Panel on Climate Change (IPCC) assessment report (IPCC, 2007). Also, all results are presented as CO_2 equivalents (CO_2e) as some of the aggregated upstream emissions factors used are reported as CO_2e and include non-CO_2 emissions, e.g., methane and N_2O. This approach was made necessary as some data sources are aggregated making updating to more recent values impossible. However, as the majority of emissions in the system are CO_2, the differences should be small.

Fig. 1 shows the detailed mining steps for both open pit and underground mining. Crude ore is delivered by diesel truck to the processing facilities, i.e., "loading and hauling" as depicted. The ore is sized, and Fe content increased if needed. High-grade ore (> 60% Fe content) requires only simple crushing and screening. The generated