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Comparison of carbon dioxide emissions intensity of steel production in China, Germany, Mexico, and the United States

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ABSTRACT

Production of iron and steel is an energy-intensive manufacturing process. The goal of this study was to develop a methodology for accurately and more fairly comparing the energy-related carbon dioxide (CO_2) emissions intensity of steel production in different countries and to demonstrate the application of this methodology in an analysis of the steel industry in China, Germany, Mexico, and the U.S. Our methodology addresses the industry's boundary definition, conversion factors, and industry structure. The results of our analysis show that, for the entire iron and steel production process, the base-case (2010) CO_2 emissions intensity was 2148 kg CO_2/tonne crude steel in China, 1708 kg CO_2/tonne crude steel in Germany, 1080 kg CO_2/tonne crude steel in Mexico, and 1736 kg CO_2/tonne crude steel in the U.S. One of the main reasons that Mexico has the lowest CO_2 emissions intensity is Mexico's large share of steel production using electric arc furnaces (EAFs) (69.4%). EAF steel production has lower CO_2 emissions intensity than production using blast furnaces/basic oxygen furnaces. China, by contrast, has the smallest share of EAF production among the four countries—9.8% in the base-case year 2010. In one scenario, we applied the Chinese share of EAF production to the other three case-study countries; the result was an increase in CO_2 emissions intensity of steel production of 19% (2036 kg CO_2/tonne crude steel) in Germany, 92% (2074 kgCO_2/tonne crude steel) in Mexico, and 56% (2703 kg CO_2/tonne crude steel) in the U.S. compared to these countries' base-case analyses. In another scenario, we applied the Chinese national average grid electricity CO_2 emissions factor from 2010, which is the highest emissions factor among the four countries, to the other three countries. In that scenario, the CO_2 emissions intensity of steel production increased by 5% in Germany, 11% in Mexico, and 10% in the U.S.

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1. Introduction

1.1. Background

Iron and steel production is an energy and carbon dioxide (CO_2) intensive manufacturing process. In the four countries investigated in this paper, two types of steel production dominate: blast furnace/basic oxygen furnace (BF/BOF) and electric arc furnace (EAF) production. BF/BOF production uses iron ore to produce steel. The reduction of iron ore to iron in a BF is the most energy-intensive process within the steel industry. EAF production re-melts scrap to produce steel. BF/BOF production is more energy intensive and emits more CO_2 than EAF production (Aichinger and Steffen 2006).

This paper describes a follow-up study to Hasanbeigi et al. (2011). In the 2011 report, we compared the energy intensity of steel production in China and the U.S. In the current paper, we have modified the methodology developed for the previous report so that we can now compare the energy-related CO_2 emissions intensity of the iron and steel industry in four countries: China, Germany, Mexico, and the U.S.

As Tanaka (2008) pointed out, "energy consumption and energy intensity are often estimated based on different definitions of an industry's boundaries, making comparison at best difficult, at worst invalid." The goal of this updated study is to modify the methodology developed in our previous study so that we can use it to accurately compare the CO_2 intensity (CO_2 emissions per unit of crude steel produced) of steel production in China,

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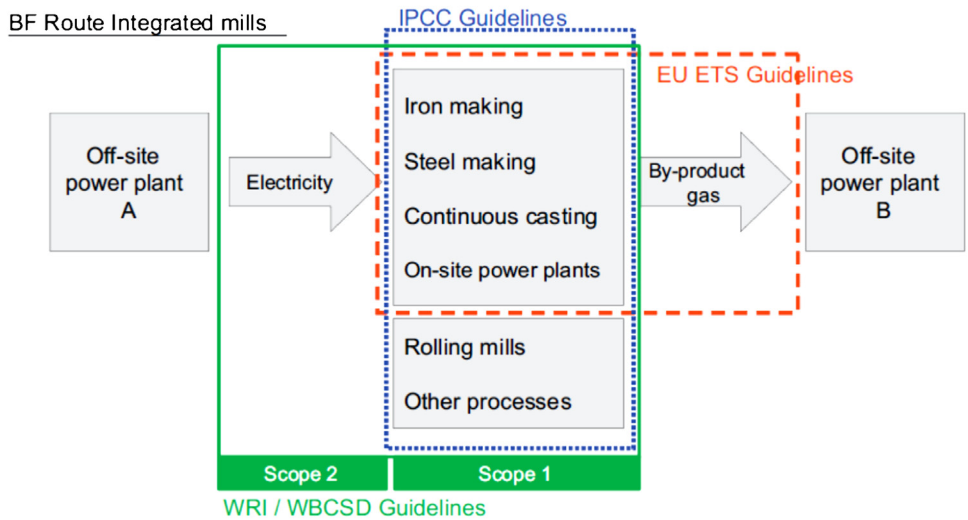

Fig. 1. Different boundary definitions in international guidelines for calculating GHG emissions of BF integrated steel plants (Tanaka 2008).

Germany, Mexico, and the U.S. Our methodology provides boundary definitions, conversion factors, and physical-versus-economic CO_2 intensity indicators to develop a common framework for comparing steel industry CO_2 emissions in these four countries. More details about the data sources, data preparation, and assumptions used in the current study are described in Hasanbeigi et al. (2011) and Appendices 1 and 2 to this paper.

Previous comparisons of international steel industry energy use and energy or CO_2 intensity have employed a range of methods. Worrell et al. (1997) found that physical indicators of steel sector energy and CO_2 intensity provided a more robust basis for comparison among countries than economic indicators. Within the range of analyses based on physical factors, a variety of study boundaries, units of analysis, and conversion factors have been used. For example, Worrell et al. (1997) use crude steel production as their unit of analysis whereas Stubbles (2000) calculated energy use and CO_2 intensity per tonne of shipped steel. Likewise, whereas Andersen and Hyman (2001) include coke-making energy use, Kim and Worrell (2002) omit coke making from their respective definitions of the industry boundary.

A review of comparison studies shows that boundary and conversion factor assumptions are not always explicitly stated and appear to vary widely, especially for characterizing imported or off-site produced inputs. Consensus has yet to form on boundaries and conversion factors for comparison of international steel production CO_2 intensity, resulting different studies producing widely disparate results that are difficult to interpret and compare. For example, Tanaka (2008) presents a case study on Japan's iron and steel industry that illustrates the critical role of proper boundary definitions for a meaningful comparison of CO_2 intensity for the steel industry. Depending on the boundaries set for the analysis, the energy use per tonne of crude steel that Tanaka calculated ranges from 16 to 21 gigajoules (GJ), which results in similar variation in CO_2 intensity. In addition, Farla and Blok (2001) studied the data for physical-energy and CO_2-intensity indicators in the steel industry and found mistakes in reported energy data, which make reliable international comparisons of countries even more difficult. Furthermore, different international greenhouse gas (GHG) accounting and reporting frameworks have set different boundaries for the iron and steel industry. Fig. 1 shows the different boundary definitions in international guidelines for GHG emissions of BF integrated steel plants (Tanaka 2008). It is clear that CO_2 intensity calculated using different guidelines – Intergovernmental Panel Climate Change (IPCC), European Union (EU) Emissions Trading System (ETS), or World Resources Institute/World Business Council on Sustainable Development (WRI/WBCSD) – cannot be compared to one another.

Policy makers often seek a single CO_2 intensity value for steel production in individual countries to aid in decision-making related to GHGs and competitiveness. However, it is difficult to provide a single CO_2 intensity value for steel production in an individual country that can then be used to compare CO_2 intensity among countries. The above analysis illustrates that such a single indicator does not provide enough information to fully explain country-specific conditions.

1.2. Overview of the iron and steel industry in China, Germany, Mexico, and the U.S

China is a developing country currently in the process of industrialization. The Chinese iron and steel industry has grown rapidly along with the national economy. In 1996, China's crude steel production surpassed 100 million metric tonnes (Mt). Since then, steel production in China has continued to increase rapidly, and for 14 continuous years China has been the world's largest crude steel producer. The average annual growth rate of crude steel production was 18.5% between 2000 and 2009. Steel production in 2010 was 637 Mt (worldsteel, 2013), representing 46.6% of world production that year. China's steel industry is a significant contributor to global CO_2 emissions.

Germany's crude steel production increased from 38 Mt in 1990 to a peak of 48 Mt in 2007, after which production dropped to 44 Mt in 2010 (worldsteel, 2013). The increase was the result of increasing production of steel in EAFs while production using the BF/BOF process remained almost constant at an annual total of approximately 30 Mt of hot metal (Stahl and Stahlinstitut, 2013). The German iron and steel industry has continuously reduced its consumption of coke in the BF by 50% over the last six decades by employing efficiency measures such as top pressure recovery turbine (TRT), pulverized coal injection, use of oxygen, etc. (Aichinger and Steffen, 2006).

Steel production in Mexico grew at 3.3% per year from 1990 to 2010, with important downturns in 2001 and 2008 associated with economic conditions. In 2010, the Mexican iron and steel industry produced 16.87 Mt of steel that accounted for 1.5% of the national gross domestic product and 8.4% of the manufacturing gross domestic product (INEGI, 2012). Steel production using EAFs accounted for the 69.4% of the total crude steel production in Mexico in 2010; the remaining 30.6% was made in BOFs (INEGI,