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Study of a low-carbon production strategy in the metallurgical industry in China

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A R T I C L E I N F O

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A B S T R A C T

Manufacturing is generally a country's largest energy consumer and CO_2 emissions producer, especially in developing regions. In particular, the steel industry, which is the pillar of the manufacturing industry, has considerable potential for energy conservation and emissions reductions. This study presents a comprehensive review of a low carbon strategy for the metallurgical industry through the application of a composition method of system dynamics and a carbon flow analysis. This study combines three different, influential factors in an innovative way. These factors are the following: 1) the iron to steel ratio, 2) the application of new technologies and 3) the recycling rate. Results indicated that first, inputting additional Electric Arc Furnace Steel is the most efficient way to achieve the goals of both energy conservation and emissions reduction, and second, because of the high price and low stocks of scrap in China, the promotion of efficient technologies (blast furnace dehumidifier saving, TRT (Blast Furnace Top Gas Recovery Turbine Unit), BFG dry dust removal technology, blast furnace coal injection technology, blast furnace COG injection technology and DRI) and the development of a circular economy are the most feasible and viable methods to reduce carbon emissions. Based on these results, a long-term roadmap toward carbon control in the metallurgical industry was developed.

1. Introduction

1.1. Background

China's iron and steel industry has burgeoned over the past several decades and has led the world market in production for the past eight years. The production of crude steel in China has grown from 95.36 million tons per annum in 2000 to 782 million tons per annum in 2013, representing an average annual growth rate of 17.57%. However, along with the rapid increase in production, came a corresponding rise in problems related to energy consumption and carbon emissions.

As a typical joint procedure industry, the entire manufacturing process for iron and steel is carbon-intensive, which makes it one of the world's major sources of greenhouse gases. Statistically, global CO_2 emissions from this industry account for approximately 5 percent of total anthropogenic emissions, while in China, these emissions account for over 12 percent. CO_2 emissions from China account for 51 percent of total metal industry emissions worldwide. In comparison, the EUcontributes12 percent, while Japan, Russia, and the United States contribute 8 percent, 7 percent, and 5 percent, respectively. All other countries contribute to the remaining 17 percent of emissions produced by the metal industry worldwide [1].

The production and energy consumption levels in China's iron and steel industry from 1995 to 2012 are shown in Fig. 1 below:

As seen in Fig. 1, the overall consumption of energy decreased from 1995 to 2012. However, even though energy consumption has declined by 40.62 percent (from 2.85×10^7 kJ to 1.69×10^7 kJ), there is still a wide gap between this figure and greater reductions achieved by other countries. The comparison between China and developed countries is displayed in Table 1.

As shown in Table 1, all emissions indices were higher in China than in developed countries in 1999. However, as improvements were implemented, energy consumption decreased considerably until 2013. Though China's emissions are not equal across time points, we estimate that energy management in China is approximately ten years behind that of advanced nations because the gap between the numbers in columns one and three is not large.

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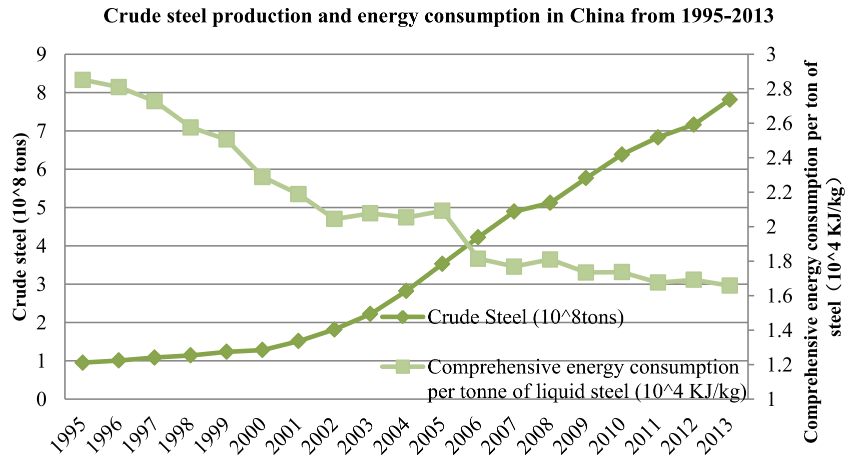

Fig. 1. Production and energy consumption in China's iron and steel industry during the period 1995 to 2013. *data source: <China Steel Yearbook> (ISSN 1003-9368), from 1995 to 2013.

1.2. Literature review

Past studies have analyzed low-carbon production in the iron and steel industry. Because the concept has been officially recognized for under20 years, few studies exist prior to this time.

Research in this area can be classified into three categories: the potential for energy savings and emissions control in China; why there are gaps between China and nations with advanced energy management, and how to improve the current situation.

An analysis of historical data using an excessive energy-input stochastic frontier model revealed that an increasing trend in energy efficiency existed in China between 2005 and 2011. During that time period, the country's average energy efficiency index was 0.699, and it had a cumulative energy conservation potential of 723.44 million tons of coal equivalent (mtce) [2,3]. In other words, while energy efficiency increased, there was even greater potential for energy savings in those seven years.

The same finding was observed with the country's carbon control efforts. The CO_2 emissions reduction potential associated with the use of cost-effective electricity was 139 t, and fuel savings potential was 11,999 PJ. Actual CO_2 emissions reductions associated with cost-effective and technical fuel savings was1191 t CO_2 and 1205 t CO_2, respectively [4].

As we can see, there remains considerable room for improvement both in energy savings and carbon control. However, before solutions for optimizing China's industry can be discussed, we must identify why this gap exists.

After comparative studies in China, Brazil, India, Mexico, South Korea, the United States and several other countries, it was determined that the recycling rate of heat, gas exhaust and other byproducts were critical indicators of carbon production levels in the iron and steel industry [5,6]. Considering China's yield rate, the utilization of raw materials is relatively efficient, with only a five percent gap between its use and that of developed countries. However, in regard to energy consumption, China's factories are nearly 20 to 40 percent more consumptive than those of other nations. In addition, the recycling rate of waste heat and energy in most of China's steel enterprises in 2006 was between 30 and 50 percent, while the recovery rate in Japan's Nippon steel industry reached 92 percent.

Table 1
Comparison of energy consumption in steel making process between China and developed countries (data source: China Steel Yearbook, 2013, P 129, Table 5).

Procedure	Energy consumption (Kgce/t)		
	China		Developed countries
	Year 2013	Year 1999	Year 1999
Coking	100.5	163	128.1
Sintering	49.14	72	58.89
Blast furnace	398.09	469	437.93
Converter	−7.17	28	−8.8
Electric oven	60.82	280	198.6
Hot rolling	51.8	155	47.82
Cold rolling	66.9		80.28

In addition to the recycling rate, the iron to steel ratio was another important indicator of energy efficiency [7,8]. China's current iron to steel ratio is excessively high. A lower iron to steel ratio means a higher scrap rate during charging, which also leads to an increased number of larger EAF (electric furnaces). EAFs are a less energy intensive way of making steel, and they emit less CO_2. In 2012, 89.8 percent of steel produced in China was made using the converter-method, while only 10.2 percent of the total 716.5 million tons crude steel produced was created using EAFs. This percentage is much lower than in other countries, such as South Korea (37.6 percent), Japan (23.2 percent), Germany (32.3 percent), Turkey (74 percent), Russia (27 percent), the U.S. (59.1 percent), Brazil (23.7 percent), and India (67.5 percent). To decrease the CO_2 emissions coming from China's steel industry, the country should encourage the construction of a large number of electric furnaces. Given the limited stock of scrap metal available, China should also consider increasing the amount of imported scrap and encourage recycling [9].

Few papers have quantified the impact such a policy would have on China's energy consumption and CO_2 emissions; therefore, we attempted to measure this impact in this study.

Based on the above review, we can assume that the recycling rate and the iron to steel ratio are two significant factors that affect carbon levels in the iron and steel industry. Several methods have to be considered to improve the status quo.

The first and most effective method is technical progress. The results of a regression analysis, a Granger causality test and an impulse response analysis indicated that technological expenditures can significantly reduce CO_2 emissions [10]. In addition, ECSC (energy conservation supply curves) revealed that in 2030, the technical energy saving potential for the Chinese iron and steel industry would be approximately 5.7 EJ, which is equivalent to 28% of the reference energy use in 2030 [11]. After studying the most