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Mode of circular economy in China's iron and steel industry: a case study in Wu'an city☆

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ABSTRACT

The iron and steel industry is a resource and energy intensive industry; in China, it also produces high pollution and emissions. Therefore, the iron and steel industry in China is inevitably developing a circular economy. This study focuses on private steel enterprises in China, whose annual pig iron output comprised more than half the total national output of 2010. Firstly, this study provides a historical perspective on the circular economy mode inherent in this sector, explains how significant reductions in energy consumption and pollutant emissions have been realized, and offers guidance for future initiatives. Then, the states of various circular economy development pathways for the Wu'an Iron and Steel Group (WISG), a typical private steel enterprise based in North China, are examined as a case study. To assess the circular economy of the WISG, an evaluation system used by this industry to estimate circular economy performance—that is, a system that uses circular economy efficiency composite index (CEECI) values—is introduced. Our results indicate that the CEECI values of the WISG were 0.72 and 0.89 in 2007 and 2010, respectively, which were lower than those of the national large and medium-sized key iron and steel enterprises (NKISE) in China. Although the implementation of a circular economy has greatly enhanced the WISG with respect to reducing pollution, further measures, such as improving the utilization rates of coke oven gas, converter gas, and converter slag, as well as reducing sulfur dioxide emissions, are urgently required. The integration of these measures into the current circumstances is not only possible in the future but is inevitably essential to achieving sustainable development in the steel industry.

1. Introduction

Iron and steel are crucial basic materials that are widely used in such industries as construction, machinery, and chemicals, in automobiles, household appliances, and vessels, and by the railway and arms industry (Michaelis and Jackson, 2000). As a pillar of the Chinese economy, the iron and steel industry has made an active contribution to China's rapid rate of growth. China's outputs of crude steel, pig iron, and iron ore in 2011 were 695, 630, and 1327 million metric tons (Mt), respectively, with respective growth rates of 8.90%, 8.43%, and 27.15% compared to 2010. China's crude steel output ranked first worldwide between 1996 and 2012—with no sign, as of the time of writing, of slipping from that spot—and in 2011, exceeded the output of the next seven ranked countries combined. In addition, the domestic consumption of crude steel in 2011 reached 632 Mt, whereas the net export of crude steel was 34.8 Mt—an increase of 7.81 Mt over 2010. These product volumes have helped satisfy the enormous demands of the domestic and overseas markets. According to Chenery's industrialization period theory, domestic consumption should be fairly steady over the next few decades, given that China's economy has entered the middle stage of industrialization—a stage characterized by rapid development of heavy industry (Chenery, 1970). In addition, China is reaching an advanced stage of urbanization, as China's urban population was 51.3% of the total population in 2011. The rate of increase in urban population is insufficient to reach the targeted

☆ Abbreviations used within this paper: circular economy efficiency composite index (CEECI); circular economy efficiency index (CEEI); national large and medium-sized key iron and steel enterprises (NKISE); Wu'an Iron and Steel Group (WISG).

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level of approximately 60% by 2020, that is, 800–900 million people, as planned by the Chinese government (Wang, 2005). Further development of heavy industry and the accelerated promotion of urbanization have promoted the rapid development of China's steel industry.

The iron and steel industry is intensive in terms of its use of technology, capital, resources, and energy. Its healthy development requires the comprehensive balancing of many disparate external conditions, including adequate supplies of iron ores, water, and coke, as well as advanced technologies and appropriate policies (Michaelis and Jackson, 2000; Yei, 2007). Currently, a large gap exists between the average levels of the domestic iron and steel industry and those of the advanced international industries in aspects such as technology, comprehensive resource utilization rates, and waste management. This underdevelopment by the Chinese industry has been directly responsible for the large proportion of inefficient resource consumption and substantial emissions of sulfur oxides (SO_x), carbon dioxide (CO_2), and dust (Streets and Waldhoff, 2000; Wang and Zhang, 2007; Xu and Wang, 2007). Meanwhile, because key raw materials—such as iron ore and water—are so limited, China must focus on the development of its iron and steel industry, especially with regard to technology upgrades and structural adjustments, to reduce the gap between the country's current and potential economic positions This approach was emphasized in the *Steel Industry Restructuring and Revitalization Plan* (2009) for China's steel industry issued by the Chinese Office of the State Council for the years 2009–2011. The document, which is a comprehensive response to the current global economic crisis, states that great efforts should be taken to develop iron and steel as "green products" by increasing resource efficiencies and minimizing environmental impacts in accordance with the spirit of a circular economy.

The concept of a circular economy was first introduced by two British environmental economists, Pearce and Turner (1990), who proposed a closed loop of material flows within an economy. It was developed using an analysis of the relationship between economic and natural systems (Su et al., 2013). The concept of the circular economy in China is similar to the concepts inherent in the Japanese and German recycling economies (Troschinetz and Mihelcic, 2009; Xu, 2007), which are based on the principles of "reduce, reuse, and recycle." A circular economy is a mode of economic development that aims to protect the environment and prevent pollution, thereby facilitating sustainable economic development. Many studies have shown that the development of a circular economy is important to mitigating environmental impacts at source and to reducing overall waste and resource consumption per unit of output by saving, reusing, and recycling resources (Geng et al., 2009; Hu et al., 2011; Li et al., 2010).

To conform to trends vis-à-vis the global ecology and circular economy, China's steel enterprises are actively exploring the circular economy development mode. In doing so, the main players are discussing and determining a new road to industrialization that features high levels of technology and economic benefits and low levels of resource consumption and environmental pollution. Many Chinese scholars have conducted extensive research into these subjects, detailed as follows.

With respect to macro-level studies of the iron and steel industry's circular economy development mode, some scholars believe it will gradually form two main modes: the city development mode and the harbor development mode (Bao and Zhu, 2007; Yin and Zhang, 2005). Assuming that the eco-industrial park is the development carrier of a circular economy, some scholars believe it is inevitable that the eco-industrial park development mode will be embraced (Cao et al., 2006; Liu, 2008; Ren and Geng, 2008). In undertaking enterprise-specific studies of the iron and steel industry's circular economy development mode, Cui and An (2008) determined that the circular economy development mode of the Hebei Iron & Steel Group used the practices of Tangshan Iron and Steel and Handan Iron and Steel to develop their harbor development mode and city development mode, respectively. Meanwhile, Gao et al. (2007) stated that the circular economy development mode of the Hebei Iron & Steel Group should be built on three pillars: inter-enterprise material circulation, regional circulation, and social circulation. Based on research into the theory of industrial circular economy, Wang (2009) indicated that establishing an eco-industrial park would be the best development mode for the Anshan Iron & Steel Group to adopt.

However, these studies mainly focus on national large and medium-sized key iron and steel enterprises, and few studies have specifically examined private enterprises. Compared to the stated-owned large and medium-sized steel enterprises, the output of private enterprises accounted for more than half of China's total output in 2010. Thus, it is imperative that private steel enterprises develop a circular economy by embracing the use of such devices as appropriate technology, equipment, and a reasonable industrial structure.

This study provides detailed information on the mode of circular economy in an old steel production base—one that represents exemplary energy-efficient practices. This is a case study on the Wu'an Iron and Steel Group (WISG), which was subjected to an industry-specific evaluation system of circular economy performance. Finally, according to our evaluation results, we stress ways in which the WISG can further strengthen its circular economy, and by which the overall Chinese steel industry can improve itself. The results of this study may be helpful for environmental protection, regulation, and management agencies in generating the background information needed for informed policy-making decisions.

2. Current status of China's steel industry

2.1. Consumption of crude steel

As the largest developing country in the world, China's rates of industrialization and urbanization have driven its rapid increase in crude steel consumption. Fig. 1 illustrates China's consumption of crude steel from 2002 to 2011. The average growth rate of crude steel consumption reached 14% in the first decade of the 21st century, and the consumption of crude steel in 2011 was triple that of 2002.

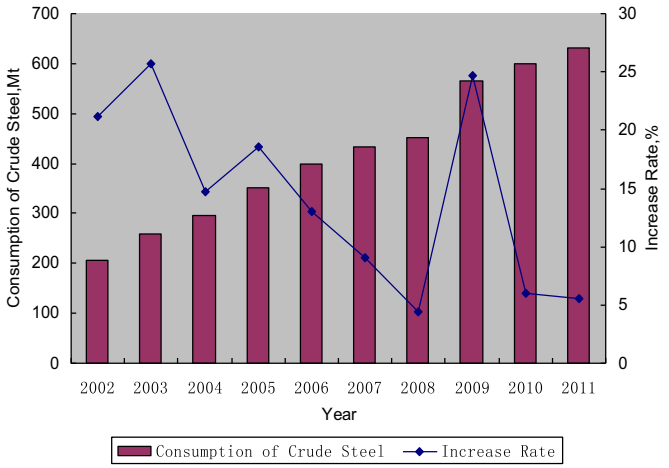

Fig. 1. Consumption of crude steel in China, 2002–2011.
Source: China Steel Yearbook, 2003–2012