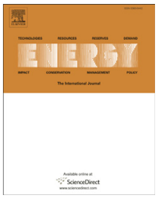
Energy 78 (2014) 333–345

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy



# Co-benefits of energy efficiency improvement and air pollution abatement in the Chinese iron and steel industry

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ARTICLE INFO

*Article history:*
Received 21 February 2014
Received in revised form
22 September 2014
Accepted 5 October 2014
Available online 31 October 2014

*Keywords:*
Co-benefits
Energy efficiency
Iron and steel industry
GHGs (greenhouse gases)
Air pollutants
Investment

ABSTRACT

In 2010, China was responsible for 45% of global steel production, while consuming 15.8 EJ of final energy and emitting 1344 Mt $CO_{2eq}$, 8.4 Mt of PM (particulate matter) emissions, and 5.3 Mt of $SO_2$ emissions. In this paper we analyse the co-benefits of implementing energy efficiency measures that jointly reduce greenhouse gas emissions and air pollutants, in comparison to applying only air pollution control (end-of-pipe technology). For this purpose we construct ECSC (energy conservation supply curves) that contain potentials and costs of energy efficiency measures and implement these in the GAINS (greenhouse gas and air pollution interactions and synergies) model. Findings show that the technical energy saving potential for the Chinese iron and steel industry for 2030 is around 5.7 EJ. This is equivalent to 28% of reference energy use in 2030. The emissions mitigation of GHGs (greenhouse gases) and air pollutants in BAEEM_S3 scenario would be reduce 27% $CO_2$eq, 3% of PM, and 22% of $SO_2$, compared to the BL scenario in 2030. Investments and cost savings were calculated for different scenarios, showing that energy efficiency investments will result in significant reductions in air pollution control costs. Hence, Energy efficiency measures should be integrated in air quality policy in China.

## 1. Introduction

The iron and steel sector is globally the largest industrial energy consumer and largest emission source of greenhouse gas and air pollutants. In 2006, the Chinese iron and steel industry is the third largest emitter for $SO_2$ (sulphur dioxide), $NO_x$ (nitrogen oxides), and PM (particulate matter) emissions in China, which amounted to 10%, 15% and 10%, respectively. In China fewer control options (e.g., desulfurization technology) and less strict pollution standards were adopted, compared with the US [1]. With the rapid Chinese industrialization, crude steel production has increased from 95 Mt in 1995 to 639 Mt in 2010, which is about 6.7 times that in 1995 while the average annual growth rates amounted to 13.8% from 1995 to 2010. This implicated that the share of crude steel production from China jumped from 12.7% in 1995 to 45.1% in 2010 of the world total, as shown in Fig. 1 [2,3]. As a pillar industry in China, the iron and steel industry consumed 15.8 EJ of final energy and emitted 1344 Mt $CO_{2eq}$, 8433 kt of PM and 5279 of kt of $SO_2$, respectively in 2010[1] [4]. The energy consumption and emissions are expected to grow further in the future because of continuing production growth [5].

Recently, the Chinese iron and steel industry has made much progress in improving energy efficiency and reducing air pollutants [6]. In the 11th Five Year Plan period (2006–2010), the Chinese government provided financial rewards for companies to help implement best available energy efficiency measures, end-of-pipe control technologies, and phasing out inefficient facilities. During that period, the amount of energy efficiency investment in the iron and steel industry reached 14.7 billion $, which accounted for 18.7% of total industrial energy efficiency investments [7–9]. Around 1.2 EJ of energy was saved and 140 Mt of $CO_2$ emission were avoided, in five years. The investment costs per unit final energy saved with and without CHP (combined heat and power) were 13.10 $/GJ and 12.51 $/GJ, respectively (see Table 1). In the 12th Five Year Plan period (2011–2015), the Chinese government set tough targets to improve energy efficiency and reduce greenhouse gas emissions, as well as air pollutant emissions in manufacturing sectors. Under the new targets, the energy intensity and carbon intensity of the iron

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[1] The emission of greenhouse gas and air pollutant are based on our calculation through GAINS.

http://dx.doi.org/10.1016/j.energy.2014.10.018

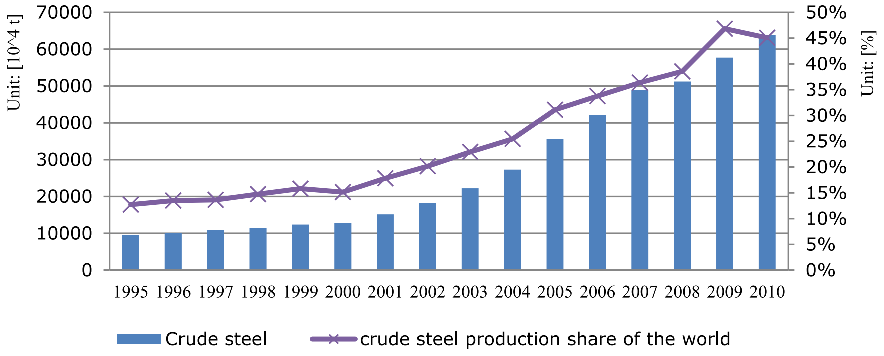

**Fig. 1.** Chinese crude steel production and share of the global from 1995 to 2010.
Source: [2,3].

**Table 1**
Energy efficiency investment of the Chinese iron and steel industry, 2006–2010.

| | Unit | 2006–2010 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|
| *I&S investment* | | | | | | | |
| I&S investment (without CHP) | 10ˆ9 $(billion) | 9.54 | 0.10 | 0.86 | 1.78 | 3.43 | 3.38 |
| CHP investment | 10ˆ9 $(billion) | 5.13 | 0.05 | 0.46 | 0.96 | 1.85 | 1.82 |
| *Energy saving* | | | | | | | |
| Energy savings no CHP total | PJ | 762.6 | 7.8 | 68.6 | 142.1 | 274.3 | 269.8 |
| Energy savings CHP total | PJ | 391.9 | 4.0 | 35.2 | 73.0 | 141.0 | 138.6 |
| *Energy efficiency investment* | | | | | | | |
| Energy efficiency investment-no CHP | $/GJ | 12.51 | 12.51 | 12.51 | 12.51 | 12.51 | 12.51 |
| Energy efficiency investment CHP | $/GJ | 13.10 | 13.10 | 13.10 | 13.10 | 13.10 | 13.10 |
| *$CO_2$ savings* | | | | | | | |
| $CO_2$ savings no CHP | 10ˆ6 t | 102.9 | 1.1 | 9.3 | 19.2 | 37.0 | 36.4 |
| $CO_2$ savings CHP | 10ˆ6 t | 37.1 | 0.4 | 3.3 | 6.9 | 13.3 | 13.1 |
| *Cost per $CO_2$ abated* | | | | | | | |
| Cost per $CO_2$ abated-no CHP | US$/t $CO_2$ | −16.8 | −16.8 | −16.8 | −16.8 | −16.8 | −16.8 |
| Cost per $CO_2$ abated-CHP | US$/t $CO_2$ | 8.3 | 8.3 | 8.3 | 8.3 | 8.3 | 8.3 |

Notes: 1) The data for energy efficiency investment and energy saving are calculated from Refs. [7,8,11].

and steel industry should decrease by 18% in 2015, compared to 2010 level. Also $SO_2$ per unit of industrial added value should be reduced by 39% [5]. To achieve these targets, the NDRC (National Development and Reform Commission) and other departments announced the mandatory Top-10,000 Program, which aims to improve energy efficiency and reduce related emissions through implementation of best available energy efficiency measures [10]. For this purpose, over 15 Billion $[2] investments will be needed to accelerate the implementation of advanced energy efficiency measures and phase out inefficient facilities [7–11].

Various authors have studied the iron and steel industry in China while focussing on different themes (e.g., energy efficiency, GHGs (greenhouse gases) and air pollutants emission) and scopes (e.g., global, national and sector) [12–19]. Early research mainly focused on the impacts of institutional changes, productivity performance and technical efficiency before and after economic reform [20–25]. Also, the characteristics of production, energy consumption and energy efficiency were evaluated on a process level [26–29]. All found that the increase of the production scale caused a rapid growth of energy consumption and related emissions. The reduction potential of air pollutants was assessed on a sector level, demonstrating that combining end-of-pipe technologies with other measures (e.g. structural adjustments and advanced technology) is the best approach to control $SO_2$ emissions [30]. Some research shows that end-of-pipe measures/policies might produce conflicting effects in the reduction of energy use and related $CO_2$ emission (e.g. desulfurization technology) [31–33]. Coal as an important energy are used in Chinese iron and steel industry, but also a major source of air pollutants. This means that the adoption of energy efficiency measure could not only reduce energy consumption and air pollutant emission but also decrease the extra energy consumed by end-of-pipe options to control air pollutant emissions. However, most of these studies do not quantify the co-benefits of energy savings and emissions mitigation by implementing energy efficiency measures. This means that the possible synergy of policies addressing energy and emission challenges is not clear to policy makers. Therefore, we attempt to address this gap by assessing the impact of best available energy efficiency technologies on air pollutant reduction in China's iron and steel industry. This can provide a guide for China's policy makers about how co-benefits can reduce the emissions of air pollutants through energy efficiency measures and how much costs would be avoided. In this study we construct ECSC (energy conservation supply curves) that contain potentials and costs of energy efficiency measures in the Chinese iron and steel industry. In order to assess the impact on air pollutant emissions and costs, we implement these curves into the GAINS (greenhouse gas and air pollution interactions and synergies) model. This paper is structured as follows. In Section 2, the GAINS (greenhouse gas and air pollution interactions and synergies) model, and data sources are described. Next, the ECSC was made to examine the costs and benefits of the energy efficiency measures. The results of the ECSC were introduced exogenously to the GAINS model to estimate energy savings, and emissions reductions of GHGs and air pollutants.

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[2] The data was calculated based on investments in total industry and the trend in the last five years.