Applied Energy 184 (2016) 171–183

Contents lists available at ScienceDirect

Applied Energy

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

Cost and potential of energy conservation and collaborative pollutant reduction in the iron and steel industry in China

Xuecheng Wu, Liang Zhao, Yongxin Zhang, Lingjie Zhao, Chenghang Zheng *, Xiang Gao, Kefa Cen

State Key Laboratory of Clean Energy Utilization, Zhejiang University, Hangzhou 310027, China

HIGHLIGHTS

- The research considers both energy conservation and pollutant emission reduction.
- The data of 24 advanced technologies are collected for calculating supply curves.
- Weight factors can affect the cost-effectiveness of these technologies.
- Conservation and emission reduction supply curves of three key areas are analysed.
- The BTH region has the largest cumulative reduction potential.

ARTICLE INFO

Article history:
Received 25 April 2016
Received in revised form 29 August 2016
Accepted 26 September 2016

Keywords:
Iron and steel
Energy conservation
Pollutant emission reduction
Supply curves

ABSTRACT

This study investigated the cost and potential of energy conservation and collaborative pollutant emission reduction in the iron and steel industry in China. A total of 24 technologies were selected, and their investments, operation costs, energy saving benefits, abatement benefits, abatement coefficients and popularising rates were collected and calculated using the 2013 data as the baseline. A new parameter, AP_{eq}, reflecting the characteristics of energy conservation and multi-pollutant collaborative emission reduction was set up. The conservation and emission reduction supply curves (CERSCs) were analysed. These 24 technologies resulted in the abatement of SO_2, NO_x, PM_{10}, CO_2 and AP_{eq} to 621.6 kt, 398.9 kt, 390.2 kt, 291.1 Mt and 699.5 kt, respectively. The influences of discount rates and weight factors on the abatement supply curves were also discussed. Results show that, with the increase in the discount rate, the abatement costs increase and the amount of that abatement cost below zero decreases. Finally, the pollutant reductions in three key areas in China were analysed. The reduction potentials of the Beijing–Tianjin–Hebei region, Yangtze River Delta and Pearl River Delta are 107, 79 and 13 kt, respectively, and the corresponding abatement costs are 7.52, −51.54 and −1.76 billion Yuan. Policymakers can choose suitable and economic technologies according to the calculation of the CERSCs.

1. Introduction

The iron and steel manufacturing industry in China is developing rapidly with the urbanisation process. From the statistics of the World Steel Association [1], crude steel production in China was up to 822.7 million tons in 2014, which accounted for 49.3% of global production. The average annual growth rate of pig iron and crude steel in China was 12.5% from 1998 to 2014. Fig. 1 shows the production of iron and steel products over the years in China [2].

The iron and steel industry is one of the largest energy-consuming sectors in China and accounts for 14–20% of the annual energy demand in China during 2000 and 2013 [3]. The total energy consumption of this industry was 688 million tons of coal equivalent (TCE) in 2013, which accounted for 16.5% of the total energy consumption in China [4]. As shown in Fig. 2, the energy consumption of the iron and steel manufacturing industry has increased year by year since 2000, but the proportion of the national total energy consumption decreased after it reached its peak value in 2009, which was related to its slower development and the overall development of other industries.

Chinese iron and steel companies have struggled to implement practices to reduce their energy consumption and carbon dioxide (CO_2) emissions because of increasing energy scarcity and pressures from climate change. Undoubtedly, energy efficiency, urbanisation and economic growth have a significant effect on CO_2 emissions [5–7]. The iron and steel industry is one of the most important air pollutant emission sources in China. Iron and steel

* Corresponding author.
E-mail address: zhengch2003@zju.edu.cn (C. Zheng).

http://dx.doi.org/10.1016/j.apenergy.2016.09.094

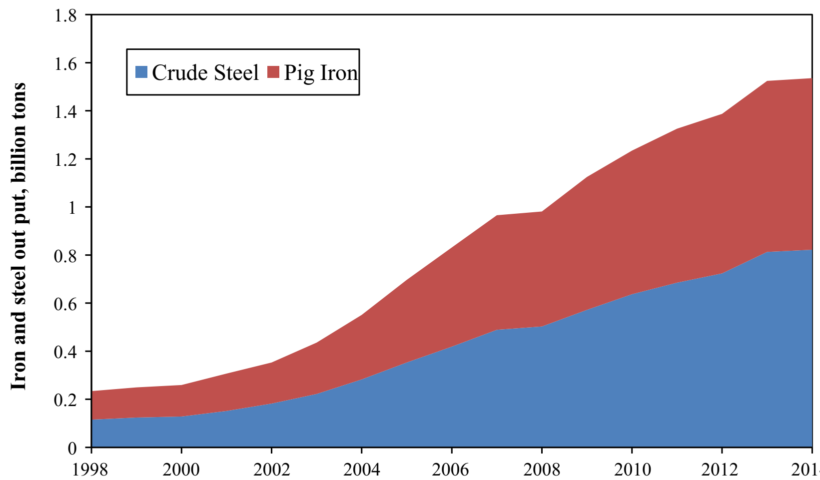

Fig. 1. Iron and steel output in China.

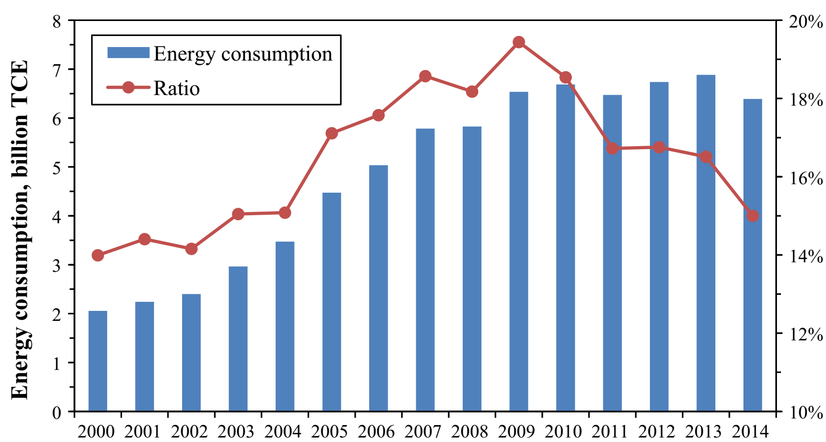

Fig. 2. Energy consumption and ratio of the iron and steel industry in China.

products consume a large amount of energy and discharge a large quantity of pollutants, making it one of the most important factors that cause regional air pollution problems. The pollutants originating from productive processes in the iron and steel industry are various and complicated. These pollutants include sulphur dioxide (SO_2), nitrogen oxide (NO_x), particulate matter (PM), polychlorinated dibenzodioxins (PCDDs) and volatile organic compounds (VOCs). Greenhouse gases, such as CO_2 and CH_4, cannot be ignored either. Many studies have shown that acute and chronic exposure to NO_x, PM and SO_2 are positively and significantly associated with increases in mortality and morbidity [8,9]. Many researchers were devoted to predicting and reducing the three main air pollutant emissions, and their achievements are important and will provide significant help in the reduction of emissions in the iron and steel industry [10–15]. Other pollutants mentioned previously also have severe effects on environmental and human health. However, no official laws or regulations in China limit these pollutants. Without an integral trade market, analysing the benefits and profits of reducing emissions is difficult. In this study, we mainly focus on the three main air pollutants.

Many studies focused on the advanced technology in iron and steel industry. The waste heat recovery and utilisation technologies, which consider the heat recovery rate and cooled slag particles with high quality and high addition value, will be key to achieving sustainable development [16]. Methanol production from steel-work off-gases and biomass-based synthesis gas can be made economically feasible and may result in environmental benefits and energy efficiency improvements [17]. Producing precipitated calcium carbonate by utilising steelmaking slags for CO_2 fixation is comparable to the conventional methods [18]. Substitution between energy and classical factor inputs in the Chinese steel sector has also drawn the attention of researchers [19]. The aforementioned studies provide the latest technological progress information on the iron and steel industry.

Many studies also focused on energy saving and emission abatement analysis in the iron and steel sector. Some studies focused on the analysis of the different sector levels, such as the enterprise, city, provincial and regional levels, which provide us a comprehensive understanding of energy conservation and CO_2 emissions in the country [20–22]. The cost and benefit of energy efficiency and emission abatement have attracted considerable attention [23,24]. These studies conducted important work regarding energy saving and pollutant reduction in the iron and steel industry in China, but focused more on the costs of energy conservation or the benefits of reducing pollutant emissions [25]. Studies focusing on the co-benefits of energy conservation and emission reduction are still rare. Energy conservation and emission reduction are the two themes of environmental protection, and many advanced technologies are equipped with both efficacies [26]. Analysing the co-benefits of the energy conservation and emission reduction of specific technologies can provide useful information on the best available technologies in different situations.