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Diffusion of energy efficient technologies in the German steel industry and their impact on energy consumption

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ABSTRACT

We try to understand the role of technological change and diffusion of energy efficient technologies in order to explain the trend of energy intensity developments in the German steel industry. We selected six key energy efficient technologies and collected data to derive their diffusion since their introduction in Germany. Since all technologies have been applied in Germany for more than 30 years we would expect complete diffusion. We found complete diffusion only for basic oxygen furnaces and continuous casting. Newer technologies (i.e. basic oxygen furnace gas recovery, top pressure recovery turbine, coke dry quenching and pulverized coal injection) diffused quicker in the initial phase but then diffusion slowed down. Key improvements in energy efficiency are due to electric arc furnaces (24%), basic oxygen furnaces (12%), and continuous casting (6%) between 1958 and 2012. The contribution of top pressure recovery turbines, pulverized coal injection and basic oxygen furnaces gas recovery accounts in total of about 3%. If the selected technologies were diffused completely, the future energy consumption could be reduced by 4.5% compared to 2012. Our findings suggest that our selection of six technologies is the key driver for energy intensity developments within the German steel industry between 1958 and 2012.

1. Introduction

Previously we studied the energy intensity development of processes in the German steel industry between 1991 and 2007, i.e. the period after German reunification and before the economic crisis in 2008/2009 [1]. We found that only the primary energy efficiency of rolling improved by about 2% per year. In blast furnaces, the specific energy consumption decreased due to an increased production and recovery of its top gas. In other processes (i.e. sinter production, steelmaking, and electric arc furnaces) we found changed energy intensity, but no continuous improvements.

In this paper we try to understand the role of technological change and diffusion of energy efficient technologies to explain the trend in energy efficiency improvements. Historic diffusion rates and the impact of these technologies on energy intensity developments should be considered for both an accurate estimation of remaining energy efficiency potentials as well as for policy design. This paper aims to shed some light on the diffusion of key energy efficient technologies in the German steel sector and the impact of these technologies on energy intensity developments. We further give an estimation of the remaining energy efficiency potential for the assumption the investigated technologies were diffused completely.

In literature, the diffusion of continuous casting machines (CCM) and basic oxygen furnaces (BOF) is well known (e.g. Refs. [2–4]). The diffusion of top-pressure recovery turbines (TRT) and coke dry quenching (CDQ) has been studied in detail for China and Japan (e.g. Refs. [5,6]). Still little has been published on the diffusion of pulverized coal injection (PCI) and BOF gas recovery (BOFGR) and the overall contribution of diffusion to energy efficiency improvement. Also, little is known about the diffusion of energy efficient technologies in the German steel sector and impact on energy use. Today, many analyses of the energy efficiency potentials use experts' judgements on diffusion rates (e.g. Ref. [7]).

This paper aims to study the diffusion of key energy efficient technologies in the steel industry and their impact on energy intensity. We evaluate whether the diffusion of energy efficient technologies follow an s-shaped curve, as proposed by Tarde [8]. We selected six technologies and collected data to derive their diffusion since their introduction in Germany. We present diffusion rates of the technologies which were introduced between the 1950s and the early 1980s. The technologies belong mainly to the

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primary steelmaking route. All technologies have been applied in the German steel industry for more than 30 years. Hence, we would expect complete diffusion of all technologies. The technologies are the basic oxygen furnace (BOF), continuous casting machines (CCM), top-pressure recovery turbine (TRT), basic oxygen furnace gas recovery (BOFGR), coke dry quenching (CDQ) and pulverized coal injection (PCI). We estimate the impact of the diffusion of these technologies and electric arc furnaces (EAF) on the primary energy consumption per ton crude steel over the whole period. Finally, we estimate the remaining energy efficiency potential for the case the investigated technologies reached complete diffusion. The paper provides analysts and policy advisors with a deeper understanding of the diffusion of energy efficiency technologies in heavy industries and the impact on energy intensity. The paper is organized as follows. Section 2 provides a review of the literature on the diffusion of technologies and steel sector specific diffusion studies. The methodology and the results of the investigated technologies are presented in Sections 3 and 4. The final section provides conclusions.

2. Literature review

Research on the diffusion of innovations over the recent decades provides a large amount of literature. Fundamental research has been done by Rogers [8]. He defined four elements of diffusion (i.e. the innovation, communication channels, time, and a social system) and analyzed the generation and implementation of innovations in detail. Freeman and Soete [9] analyzed the impact of industrial innovations from the perspective of the firm as well as from a macro-economic perspective. They found that the firm size has an impact on the adoption of innovations. Tarde [8] found that the rate of adoption of a new idea usually follows an s-shaped curve over time.

The diffusion of the BOF has been studied, both using data on the national level (e.g. Refs. [10,11]) and on the plant level (e.g. Refs. [4,12]). Rosegger [12] gave an in-depth analysis of the diffusion of BOF in comparison to its predecessor, the open hearth furnace (OHF). He took a sample of five U.S. steel companies and investigated the characteristics of the newly introduced BOF concerning its expected effects, costs, and system-specific conditions. Oster [4] found that large firm size accelerate the diffusion of innovation in the steel industry. Though, according to her findings, the diffusion of the BOF in the U.S. steel industry is much slower than in the Japanese steel industry. Poznanski [10] studied the fade out of OHF that were substituted by BOF. According to his findings extinguishing an obsolete process technology in the steel industry takes about 13 years. The pace of extinguishing the OHF has an impact on the diffusion rate of its successor (i.e. BOF). Ray [11] studied the diffusion of mature technologies in industry, which are not necessarily energy efficient technologies. Among other technologies he studied the BOF and CCM. Overall, he found three major factors driving the diffusion of technologies: profitability, management's attitude towards innovation, and access to capital.

Worrell and Biermans [13] tracked the diffusion of new EAF plants in the U.S. between 1990 and 2002. They established a database on each individual EAF plant covering information such as production capacity, year of start-up and electricity use. They found that stock turnover and retrofit are essential parameters in energy efficiency improvements, since new plants are more efficient than older plants. Furthermore, they found the impact of stock turnover to be more important than the impact of retrofit. Moya and Pardo [14] collected data of the steel industry on the plant level of all EU-27 member countries. In their model the future diffusion of energy efficiency technologies depends on the development of the payback period. They find a strong diffusion of BAT from 2010 to 2013 which to their findings will lead to a reduction of 0.27 t CO_2/t crude steel or 3.6% per year.

Studies on other energy efficiency potential use experts' judgements on the diffusion of current energy efficiency technologies. Tanaka et al. [7] estimate the remaining global energy efficiency potential for the steel industry. Oda et al. [5] developed a world energy model which models steelmaking routes in detail. Besides considering current energy efficiency technologies it also includes emerging technologies. To model the future diffusion of the technologies they assume diffusion rates for the selected technologies for the year 2000 and for each investigated region or country. For the non-policy scenario they find a worldwide diffusion of about 50% for TRT and CDQ and a 42% diffusion of BOFGR for the year 2015. All calculated diffusion rates are increasing continuously. Okazaki and Yamaguchi [6] estimate the possible overall CO_2 emission reduction potential of selected technologies in the steel industry. They assume full diffusion of these technologies and calculate the CO_2 reduction.

In summary, most studies on the diffusion of EET in the steel industry focus on one or two technologies. The diffusion of BOF and CCM has been studied in detail, as for these technologies statistics are available, in contrast to other technologies. The diffusion of TRT and CDQ has been studied mainly for China and Japan (e.g. Refs. [5,6]). So far, there are no studies that estimate the diffusion rates of EET for the steel industry in Germany.

Our paper provides an in-depth analysis on the diffusion of six key energy efficient technologies for the iron and steel industry in Germany using both data on the national level and on the plant level. Our study covers a time period of 60 years. We explain the impact of these technologies on the energy intensity development. Based on the diffusion rates we estimate the remaining energy efficiency potential if all technologies were diffused completely.

3. Methodology

3.1. Diffusion rates

We focus on proved and key energy efficient technologies (EET). We select energy efficient technologies exceeding a specific energy saving potential of 0.1 GJ/t of product in order to detect an effect on the primary energy consumption per ton crude steel. The energy intensity of the steel industry often is expressed as energy consumption per tonne crude steel. This approach does not distinguish between the two main steelmaking processes, i.e., BF/BOF and EAF steelmaking route.[1] The EAF steelmaking route consumes only about one third of the energy of BF/BOF steelmaking. Thus, we include the diffusion of EAF steelmaking in the analysis of the impact of the diffusion of EET on the specific energy consumption.[2]

We developed the diffusion rates based on two approaches. For the diffusion rates of BOF, CCM, PCI, BOFGR and EAF we collected data on the national level, such as steel produced by CCM or coal input to blast furnaces. The diffusion rates of TRT and CDQ are established using data on the plant level. We set up a database with all blast furnaces and coke ovens which were operated from 1979 or 1984, respectively, until today. We collected data of all entries and exits of the respective plants in the investigated timeframe. Then we collected data in which year the selected technology was installed or removed from that plant following the approach by Worrell and Biermans [13]. We used sources such as reports and databases by the Steelinstitute VDEh, scientific papers, press

[1] For a description of the two steelmaking processes, see e.g. Ref. [1].

[2] To our understanding EAF steelmaking is not an energy efficient technology since it cannot completely replace primary steelmaking.