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Variables affecting energy efficiency and CO_2 emissions in the steel industry

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ABSTRACT

Specific energy consumption (SEC) is an energy efficiency indicator widely used in industry for measuring the energy efficiency of different processes. In this paper, the development of energy efficiency and CO_2 emissions of steelmaking is studied by analysing the energy data from a case mill. First, the specific energy consumption figures were calculated using different system boundaries, such as the process level, mill level and mill site level. Then, an energy efficiency index was developed to evaluate the development of the energy efficiency at the mill site. The effects of different production conditions on specific energy consumption and specific CO_2 emissions were studied by PLS analysis. As theory expects, the production rate of crude steel and the utilisation of recycled steel were shown to affect the development of energy efficiency at the mill site. This study shows that clearly defined system boundaries help to clarify the role of on-site energy conversion and make a difference between the final energy consumption and primary energy consumption of an industrial plant with its own energy production.

1. Introduction

The improvement of energy efficiency is seen as one of the most promising measures for reducing global CO_2 emissions and dependence on imported fossil fuels. Manufacturing industry accounts for one-third of global energy use (IEA, 2008a) and therefore improvement of energy efficiency and reduction of CO_2 emissions are high on the agenda of industrial actors. The iron and steel industry is one of the most energy-intensive industrial sectors and the largest emitter of CO_2 emissions. In 2005, it accounted for about 20% of global industrial energy use and 30% of energy and process CO_2 emissions from industry (IEA, 2008a). The International Energy Agency (IEA) states in the WEO-2009 report that by 2030 the energy saving and CO_2 reduction achieved by national policies and measures compared to baseline emissions[1] will be bigger in the industrial sector than in any other final energy consumption sector. The biggest emission reduction compared to baseline emissions can be achieved in iron and steel and cement sectors: more than half of the reduction of global industrial energy-related CO_2 emissions (IEA, 2009).

Many studies have considered the energy efficiency and CO_2 emissions of the iron and steel industry. International benchmarking studies (Karbuz, 1998; Farla and Blok, 2001; Phylipsen et al., 2002; IEA, 2007) on energy consumption/blast furnace reductant use and CO_2 emissions in the steel industry were found in the literature. According to a comparison of specific energy consumption among major steelmaking nations, made under the Asia Pacific Partnership (JISF, 2007), Japan and Korea are the most energy-efficient countries: the EU is 10% and 5% behind Japan and Korea, respectively. Also, the CO_2 emission reduction potentials based on best available technology are lowest in Japan and Korea, followed by OECD Europe (IEA, 2008a). However, inside the EU there are differences between countries and individual steel mills. The member companies of World Steel Association (worldsteel) are involved in benchmarking for improvements in energy use and material efficiency (worldsteel, 2008). In addition, by 2010, a global steel sector approach to reduce CO_2 emissions, including the collection and reporting of CO_2 emissions data by steel plants in all major steel producing countries, will be delivered. Unfortunately, the data on individual mills are confidential and the benchmark database is available only for the member companies of worldsteel. The benchmarking approach has also been applied in some countries, such as the Netherlands and Belgium, to allocate emission allowances under the EU emissions trading scheme (EU ETS). The possibility of using an EU-wide benchmark-based allocation methodology to the industrial sectors under international competition, such as iron and steel industry, from 2013 onwards has been studied. It has been proposed that the allocation would be based on an energy efficiency benchmark, a fuel mix benchmark, a process emission benchmark as well as activity level (Neelis et al., 2008). Also, country-specific (Sakamoto et al., 1999; Sandberg et al., 2001;

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[1] The difference between the WEO-2009 Reference Scenario and 450 Scenario (based on the target to stabilise the atmospheric concentration of greenhouse gases at 450 ppm of CO_2-equivalent).

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Nomenclature

η	efficiency of energy production
BAT	best available technology
BF	blast furnace
BOF	basic oxygen furnace
CDQ	coke dry quenching
CSPA	Canadian Steel Producers Association
E	energy consumption
EAF	electric arc furnace
EEI	energy efficiency index
EU ETS	EU emissions trading scheme
IEA	International Energy Agency
IISI	International Iron and Steel Institute
JISF	Japan Iron and Steel Federation
NRCAN	Natural Resources Canada
OECD	Organization for Economic Co-operation and Development
PLS	partial least squares projection to latent structures
r	ratio between primary energy consumption and final energy consumption
SEC	specific energy consumption
WEO	World Energy Outlook

Price et al., 2002; Ozawa et al., 2002; NRCAN/CSPA, 2007) and mill- and process-specific (Petela et al., 2002; Worrell et al., 2008) analyses have been made. In addition, potentials for reducing energy consumption and CO_2 emissions in the steel industry have been studied widely (Worrell et al., 2001; Gielen and Moriguchi, 2002). However, the principles upon which the energy consumption and CO_2 emissions have been calculated are seldom presented unambiguously. In addition, many simplifications and assumptions may have been made.

It has been found that there are many issues causing problems when energy efficiency and its development are measured. Karbuz (1998) and Farla and Blok (2001) emphasise the selection of appropriate data when energy efficiency indicators are used as a basis for policy making or international comparisons. Among others, the following potential problems were identified: the definition of system boundaries, the calorific values used, the non-energetic use of fuels, the fuel classification and utilisation of unconventional fuels, as well as the quality of data collection. In addition, double counting of the coke input and utilisation of coke oven gas and blast furnace gas occurred in some statistical sources.

Both international comparisons and national-level studies often use weighted averages for energy consumption and CO_2 emissions, and do not usually make any distinction between iron-ore-based production and recycled-steel-based production. Therefore, those studies often tell more about the structure of the steel industry than they do about the energy efficiency of steel production in a certain country.

The importance of clearly defining the system boundary has been noted in some studies, such as Larsson et al. (2004); IEA (2007) and Tanaka (2008). The study made by Tanaka (2008) showed that the specific energy consumption of crude steel production in Japan can range from 16 to 21 GJ/t, depending on the system boundaries set for the analysis and the conversion coefficient used for electricity production. One problem related to the definition of system boundaries is that the losses from self-production (or auto-production) of electricity might be included in the specific energy consumption of steel production or, alternatively, in the energy sector (Farla and Blok, 2001).

The IEA (2007) lists multiple factors that affect energy intensities, such as: (1) plant size, (2) impacts of system boundaries like buying intermediate products such as pellets, sinter, coke, scrap, oxygen and lime or buying/selling electricity and heat, (3) used technologies, such as coke dry quenching (CDQ) and continuous casting, (4) efficiency of processes such as hot stoves and recovery of blast furnace gas, (5) quality of raw materials like iron ore, coal and coke (6) level of waste energy recovery that is affected by energy prices and ambitiousness of energy policies. Kuusinen et al. (2002) stated that changes in the operating conditions of a steel mill, such as the production rate, affect the specific energy consumption, and therefore make it difficult to separate the effect of energy efficiency improvement actions from the effects of other changes.

The aim of this study is to find out how different variables affect energy consumption and CO_2 emissions in the steel industry. This is done by analysing the development of an energy efficiency index and a CO_2 index in a case mill with different definitions for system boundaries. The focus is on the measurement of energy efficiency in the iron-ore-based steelmaking process.

2. Energy consumption in the steel industry

2.1. Energy efficiency and CO_2 indicators used in industry

Energy efficiency is often defined as the ratio between the useful output of a process and the energy input into a process, as presented by Patterson (1996), or vice versa. In the process industry, such as the steel industry, the useful output is typically measured as tons of products produced. Therefore, physical-thermodynamic indicators such as specific energy consumption (SEC) are most commonly used for measuring the energy efficiency in industry. Sometimes, the terms 'energy intensity' (IEA, 2007; NRCAN/CSPA, 2007), 'energy intensity value' (Worrell et al., 2008) or 'energy consumption intensity' (Tanaka, 2008) are used instead of SEC.

Specific energy consumption (SEC) is defined as follows (EC, 2008):

$$\mathrm{SEC} = \frac{\text{energy used}}{\text{products produced}} = \frac{\text{energy imported} - \text{energy exported}}{\text{products produced}} \tag{1}$$

where SEC is measured in GJ/t.

Industrial processes often use energy in different forms, such as fuels, steam and electricity, and the SEC of that kind of processes is calculated as follows (EC, 2008):

$$\mathrm{SEC} = \frac{E_{\mathrm{Fuels}} + E_{\mathrm{Steam}} + E_{\mathrm{Electricity}}}{\text{products produced}} \tag{2}$$

where E_{Fuels} is fuel consumption, E_{Steam} is steam consumption and $E_{\mathrm{Electricity}}$ is electricity consumption of the process. Eq. (2) defines SEC as final energy consumption. If the energy consumption of steam and electricity production is taken into account, the SEC as primary energy consumption is defined according to the following equation (EC, 2008):

$$\mathrm{SEC} = \frac{E_{\mathrm{Fuels}} + \frac{E_{\mathrm{Steam}}}{\eta_{\mathrm{Steam}}} + \frac{E_{\mathrm{Electricity}}}{\eta_{\mathrm{Electricity}}}}{\text{products produced}} \tag{3}$$