Energy Policy 44 (2012) 118–129

Contents lists available at SciVerse ScienceDirect

Energy Policy

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

International comparisons of energy efficiency in power, steel, and cement industries

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ARTICLE INFO

Article history:
Received 5 August 2011
Accepted 12 January 2012
Available online 11 February 2012

Keywords:
Specific energy consumption
Steel sector
Cement sector

ABSTRACT

Industrial energy efficiency is of paramount importance both for conserving energy resources and reducing CO_2 emissions. In this paper, we compare specific energy consumption among countries in fossil power generation, steel, and cement sectors. The evaluations were conducted using common system boundaries, allocation, and calculation methods. In addition, we disaggregate within sectors, such as with blast furnace–basic oxygen furnace (BF–BOF) steel and scrap-based electric arc furnace (Scrap-EAF) steel. The results reveal that characteristics vary by sub-sector. Regional differences in specific energy consumption are relatively large in the power, BF–BOF steel, and cement sectors. For coal power generation and BF–BOF steel production, continual maintenance and rehabilitation are of key importance. We confirm these key factors identified in the previous work on our estimated numerical values. In BF–BOF steel production, corrections for hot metal ratios (pig iron production per unit of BOF crude steel production) and quality of raw materials have a large effect on the apparent specific energy consumption. Available data is not yet sufficient for straightforward evaluation of the steel and cement sectors.

1. Introduction

Industrial energy efficiency is of paramount importance for conserving energy resources, decreasing production costs, and increasing economic competitiveness as well as for international climate negotiations. In many countries, there is a great deal of interest in improving energy efficiency. For a fossil fuel importing country, energy efficiency improvement eases energy insecurity of the country. For a fossil fuel exporting country, energy efficiency improvement enhances export capacity and conservation of domestic reserves. However, it seems that there are some obstacles to the improvement of energy efficiency arising from technical, social, and financial barriers. Lack of sufficient data and data reliability could be one such barrier (e.g., IEA, 2010c). There is need for an overview of comparable energy efficiency by sector and country.

Several analyses for international comparisons of energy efficiency have been conducted. A project titled 'International Comparisons of Energy Efficiency' was initiated by Utrecht University and LBNL in cooperation with ADEME and the Fraunhofer Gesellschaft in 1994. The project revealed the importance of considering structural differences—i.e., product (quality) mix and import/export streams—for appropriate physical energy efficiency (Phylipsen et al., 1997). Worrell et al. (1997) and the Asia Pacific Energy Research Center (2000) presented information on economic and physical intensity trends in the steel sectors of several countries. Kim and Worrell (2002) indicated CO_2 emissions trends in the steel sectors of seven major steel producing countries. However, the results in the three analyses depended on structural differences (e.g., ratio of EAF steel) rather than specific energy consumption) (SEC, as noted by Phylipsen et al. (1997).

IEA (2007) discussed issues relating to the estimation of comparable SEC, such as system boundaries, allocation, and calculation methods. Tanaka (2008) calculated numerical values under different boundaries in Japan's steel sector and also pointed out the importance of system boundaries. IEA (2008b) indicated regional CO_2 emission reduction potentials in both the steel and cement sectors. IEA (2009, 2010c) indicated regional energy saving potentials. However, they did not indicate any SEC results for the steel sectors of the different countries.

For the cement sector, Battelle (2002) indicated SEC by country/region in 1990 and 2000. IEA (2007, 2009) also presented information on trends for several countries. There was a difference between the results of their analyses. IEA analyses noted the possibility of different system boundaries and measurement methods.

The first purpose of this paper is to compare SEC in the fossil power generation, steel, and cement sectors. The second purpose is to discuss sector-specific situations over the estimated SEC.

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0301-4215/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enpol.2012.01.024

The point is empirical evaluation rather than methodology development. For a comparison that allows explicit consideration of structural differences, we focus on disaggregated physical indicators such as coal and gas power generation, blast furnace–basic oxygen furnace (BF–BOF) steel and scrap-based electric arc furnace (Scrap-EAF) steel production, and clinker production. Previous studies did not disaggregate BF–BOF steel and Scrap-EAF steel. The originality of this paper is to estimate SEC in iron and steel sector by distinguishing between BF–BOF steel and Scrap-EAF under common system boundaries, allocation, and calculation methods.

Graus et al. (2007) and Borkent (2010) have conducted in-depth analyses of energy efficiency trends in fossil power generation, based on IEA Energy Balances, including a comparison of IEA statistics and national statistics. They focused on power generation by main activity producers. In this paper, both main activity producers and autoproducers are taken into account. The estimated energy efficiencies in the power sector are compared among countries in Section 2, and the characteristics of energy efficiencies will be compared among these three sectors in Section 5.

The remainder of the paper is organized as follows. Section 2 focuses on energy efficiency in fossil power generation. Section 3 gives methodology used and the results for the iron and steel sector. Section 4 provides information on methodology and the results for the cement sector. We summarize these results in Section 5. Finally, policy implications are discussed in Section 6.

2. Fossil power generation

2.1. Overview

The methodology for estimating the energy efficiency in fossil power generation is based on Graus et al. (2007), Graus and Worrell (2009), and Borkent (2010). The energy efficiency in power generation is defined as the produced energy (electricity and heat) divided by fuel input measured by lower heating value (LHV). Heat produced by CHP plant should be converted because heat extraction causes decreased energy efficiency in electricity generation. Similar to the previous works, we also use a value of 0.175 as the correction factor between heat and electricity.

In this study, we take into account not only main activity producers but also autoproducers as previously mentioned. Main activity producers generate electricity and/or heat for sale as their main business; however, autoproducers generate the same for their own consumption as a primary propose. Although worldwide power output by autoproducers accounted for 6% of total fossil power generation in 2008, in some countries the power output from fossil power generation by autoproducers accounts for a relatively large share, such as 34% in Brazil, 28% in Austria, and 16% in Spain in 2008 (IEA, 2010b).

The data used for the estimates is based on IEA Energy Balances (IEA, 2010b). In the statistics, energy input for power and CHP plants is given in lower heating value (LHV). The energy output is measured as gross production. Gross production is electricity production without subtracting electricity consumption for auxiliary equipment in a plant.

Looking at fuel categorization, we distinguish three types of fossil fuels: (i) coal and coal products, (ii) crude oil, petroleum products, and natural gas liquid, and (iii) natural gas. We call these three types of fossil fuels coal, oil, and gas, respectively. Peat-fired power generation is excluded from this analysis.

2.2. Results for energy efficiency in fossil power generation

Fig. 1 shows the estimated energy efficiency trend for coal power generation for the period from 1990 to 2008. The listed countries are sorted by average volume of coal power generation for the last three years (2006–2008), as described in the explanatory notes. In addition to the country data, EU (27) and world averages are listed for comparison.

Energy efficiencies in coal power generation have been improving in countries such as Japan, Germany, Poland, and China over these periods; however, the trends in other regions are unclear. World average energy efficiency has improved slightly, from 34% to 35%. Worldwide power output for coal power generation steadily increased from 4420 TWh/yr in 1990 to 8072 TWh/yr in the period average (2006–2008).

Regional differences in energy efficiency are relatively large. Compared to the world average heat rate (coal consumption per kWh), the value for the most efficient region was 85% in 2008. The value for the least energy efficient region shown in Fig. 1 is 135%. The least efficient region consumed 1.59 times as much coal as the most efficient region in 2008. Regional differences are driven by differences in steam conditions, fuel types used, cooling methods applied, coolant temperature, operation and maintenance, rehabilitation, and capacity factor (Graus and Worrell, 2009). The average

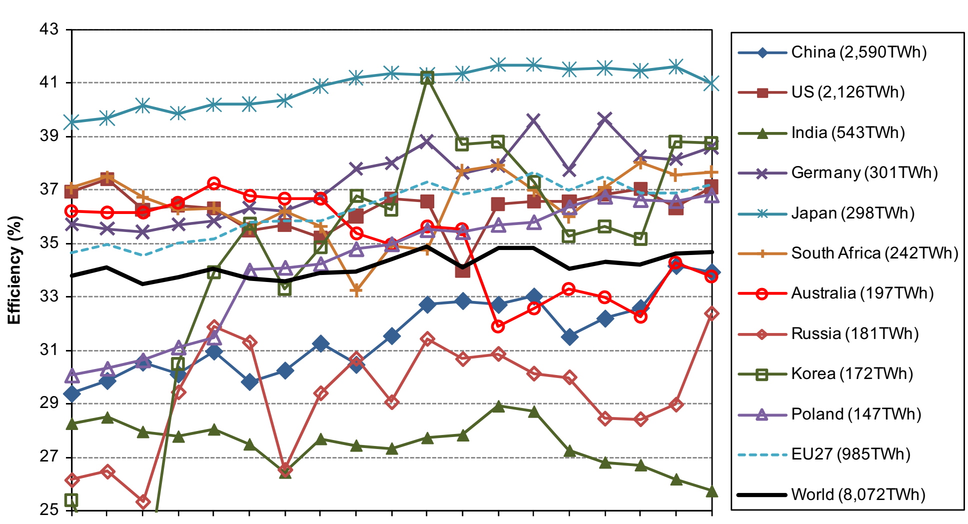

Fig. 1. Energy efficiency in coal power generation (LHV). *Note*: The values in brackets in the explanatory note denote power output for coal-fired power generation in the period average (2006–2008).