Energy 153 (2018) 816–824

Contents lists available at ScienceDirect

Energy

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

Potential energy efficiency improvements for the Brazilian iron and steel industry: Fuel and electricity conservation supply curves for integrated steel mills

Rafael Rodrigues da Silva [a, *], Flavio Roberto de Carvalho Mathias [a], Sergio Valdir Bajay [a, b]

[a] School of Mechanical Engineering, University of Campinas – UNICAMP, 13083-860, Campinas, SP, Brazil
[b] Interdisciplinary Center for Energy Planning (NIPE), UNICAMP, Cidade Universitária "Zeferino Vaz", P.O. Box 6166, 13083-896, Campinas, SP, Brazil

ARTICLE INFO

Article history:
Available online 13 April 2018

Keywords:
Energy efficiency
Energy conservation supply curve
Brazilian iron and steel sector
Specific energy consumption

ABSTRACT

The iron and steel sector is the second-largest energy consumer and main emitter of greenhouse gases in the Brazilian industry. We present a unique, detailed analysis of the energy performance of a sample of five integrated mills with internal coke production that account for over half of the crude steel produced in Brazil and identify economically viable energy efficiency measures. The analysis indicates that the specific total energy consumption of this sample of mills increased by about 13% between 2004 and 2014 and that the corresponding figure for electricity consumption was 18%. Performance and cost data on best energy practices for iron and steel production processes applicable in Brazilian mills are used to develop fuel and electricity Conservation Supply Curves. The economic potential identified for fuels was 3.02 GJ/t of crude steel, which can be achieved with nine energy efficiency measures, mainly in the iron making, sintering and steel making processes. The findings also indicate that these mills could become net exporters of electricity with an economic potential of 1.51 GJ/t of crude steel if four energy efficiency measures were implemented, particularly in the O_2 production and coke making processes.

1. Introduction

The iron and steel industry is of unquestionable importance not only because its products are in widespread use but also because it is a high-consumption, energy-intensive industry and one of the most important sources of greenhouse gases (GHG) [1,2]. Brazil is the eighth-largest steel producer, accounting for 2% of global production.[1]

The main competitive advantage of the Brazilian iron and steel sector is the abundance of high-quality iron ore reserves in the country. Brazil is responsible for 21% of worldwide production of iron ore and 24% of world iron ore exports [3]. However, 21.5 million tonnes of coal were imported into Brazil in 2015, as the Brazilian coal reserves have high ash and sulfur content and are not suitable for the steel production processes employed in the country [4,5].

Steel in Brazil is produced in three main types of mills [4]:

1. Integrated mills, which carry out the iron-ore reduction, steel-making, casting and forming processes.
2. Semi-integrated mills, which use pig iron and sponge iron produced by other mills or recycled metals for the steelmaking, casting and forming processes.
3. Independent producers, which only produce pig iron.

In 2015, Brazilian production capacity was 48.9 million tonnes of crude steel per year, of which only 68% was used.[2] Production of finished and semi-finished products was 22.6 million tonnes and 9.8 million tonnes, respectively. Of the former, 59% was flat steel products and the remainder long steel products, while 86% of the latter was slabs. Integrated mills accounted for 85% of Brazilian

* Corresponding author.
E-mail addresses: rafaelrsilva@gmail.com (R. Rodrigues da Silva), frmathias@uol.com.br (F.R.C. Mathias), bajay@fem.unicamp.br (S.V. Bajay).

[1] World steel production in 2015 was 1.615 million tonnes.

[2] In the last decade, new plants have increased Brazilian semi-finished steel production capacity (mainly of slabs). These include the Companhia Siderúrgica do Atlântico (CSA), which was set up in 2010 and has a capacity of 5 million tonnes per year, and the Companhia Siderúrgica do Pecém (CSP), which was commissioned in 2016 with an initial capacity of 3 million tonnes per year.

https://doi.org/10.1016/j.energy.2018.04.055
0360-5442/

Abbreviations

ABM	Brazilian Association of Metallurgy, Materials and Mining
AP	Technology adoption potential
B	Other annual economic benefits of efficiency measures
BOF	Basic oxygen furnace
CCE	Cost of Conserved Energy
EAF	Electric arc furnace
ECSC	Energy Conservation Supply Curve
EEP	Energy Efficiency Potential
EOF	Energy optimizing furnaces
GHG	Greenhouse gases
GJ	Gigajoule
GWh	Gigawatt-hour
i	Discount rate
M	Annual change in O&M costs
n	Lifetime of the efficiency measure
O&M	Operation and maintenance
P	Production (tp or tcs)
PJ	Petajoule
tp	Tonnes of products of each steel production process (coke, sinter, pig iron, crude steel, rolled steel)
tcs	Tonnes of crude steel
TWh	Terawatt-hour

crude steel production. The main types of furnaces used to make steel in Brazil are the basic oxygen furnace (BOF) and electric arc furnace (EAF), which account for 78.2% and 20.2% of steel production, respectively[3] [5,6].

Brazilian pig iron production in 2015 was 32.1 million tonnes, of which about 80% was produced with coke and the remainder with charcoal. Integrated mills use mostly coke for pig iron production, while independent producers use only charcoal. Pig iron is produced by integrated mills (86.6%), which use almost all the pig iron they produce for their own steel production, and by independent producers, which sell all their production. The pig iron sold is used as raw material by semi-integrated mills or exported. About 2.7 million tonnes were exported in 2015 [5,7,8]. In that year, 86% of the charcoal used by integrated mills came from their own planted forests, 10% from suppliers and 4% from certified forest residues [8,9].

The final energy consumption of Brazilian industry in 2015 was 3543.9 PJ, or 34.5% of the country's final energy consumption. The iron and steel industry is the industrial sector with the second-largest energy consumption. In 2015 its total energy consumption was 691.8 PJ, or 19.5% of industrial energy consumption, and its electrical energy consumption was 67.4 PJ (18.7 TWh), of which 45.9 PJ (12.8 GWh) were self-generated [10]. The main energy sources for the Brazilian iron and steel industry are coke and charcoal, as shown in Fig. 1 [10]. The iron and steel industry is the largest emitter of greenhouse gases of all Brazilian industrial sectors [11].

The specific total energy consumption of the Brazilian iron and steel industry has shown a downward trend in the past four decades, while the specific electrical energy consumption has remained at approximately the same level over the same period, as shown in Fig. 2.

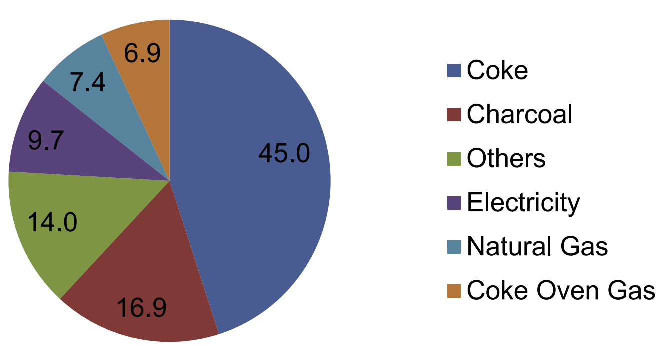

Fig. 1. Percentage share of energy sources consumed in the Brazilian iron and steel industry in 2015. Source: EPE [10].

According to the American Iron and Steel Institute and the Asia Pacific Partnership on Clean Development and Climate, energy constitutes a significant portion of the cost of steel production, ranging from 20% to 40% in some countries [12,13]. Improving energy efficiency can therefore reduce production costs and improve the competitiveness of the steel industry.

This study can be broken down into three main elements. Firstly, we analyze the energy performance of an important sample of iron and steel mills. Secondly, we assess the applicability of a series of energy efficiency measures in these mills. Finally, we create Energy Conservation Supply Curves for fuels and electricity and evaluate the cost effectiveness of these measures.

We use detailed historical energy data for five of the largest Brazilian mills. The data are broken down to the level of individual production processes in each mill, from coke production to steel finishing.

Energy Conservation Supply Curves (ECSCs)[4] are graphical representations of energy conservation potentials and their costs and have been used since the 1970s. Energy conservation

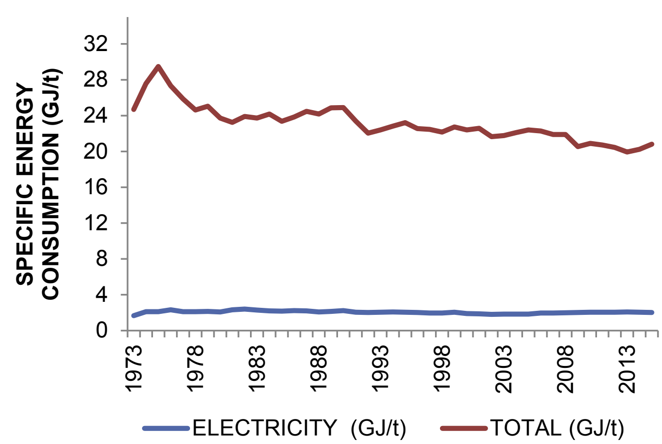

Fig. 2. Specific total and electrical energy consumption for the Brazilian iron and steel industry. Source: EPE [10].

[3] Energy optimizing furnaces (EOFs) are used for the remaining 1.6%.

[4] They are also known as Cost Curves of Conserved Energy (CCCEs), Conservation Supply Curves (CSCs), Supply Curves of Conserved Energy (SCCEs), Energy Efficiency Supply Curves (EESCs) and Cost Curves of Energy Saving (CCESs).