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CO_2 emissions mitigation strategy in the Brazilian iron and steel sector–From structural to intensity effects

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A R T I C L E I N F O

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A B S T R A C T

This study estimates the potential and costs for mitigating CO_2 emission in Brazil´s steelmaking industry. Two main scenarios were developed: (1) a reference scenario considering the actual trends of the steel industry; and (2) a scenario where the use of charcoal from planted forests is stimulated for the additional steelmaking capacity. In addition, the effects of 13 Best Available Technologies (BAT) and one disruptive technology (TGRBF) on the industrial sector were calculated for both scenarios. Findings show that the increase in charcoal usage in pig iron production from 23.0% to 32.5% can reduce the total CO_2 emissions in 11.3% in 2050, while the adoption of the BAT and TGRBF in new steel plants can reduce the CO_2 emission levels in 15.6%. If both effects are considered, the CO_2 reduction potential would reach 23.2% in 2050. As the TGRBF technology was developed to a coke based-route, a simply structural change towards charcoal (without using BATs) can be less effective in reducing cumulative CO_2 emissions than applying BATs in a scenario without structural change. However, in terms of costs, the switch towards an increasing use of charcoal is less expensive. Correct incentives are needed in the industry to achieve such reduction levels.

1. Introduction

The steelmaking production is a major sector of the world's industrial activity, being one of the most energy intensive processes of the world (WSA, 2014). About 1.6 billion tonnes of steel are produced yearly in the world, being 50% of this amount produced by China (Li and Zhua, 2014). On average, 1.8 t of CO_2 are emitted for every ton of steel produced. As such, the iron and steel industry accounts for approximately 6.7% of total world CO_2 emissions (IEA, 2015). It is estimated that 75% of the CO_2 emissions from steelmaking comes from the production of pig iron in the blast furnace, during the reduction process; the remaining percentage is the result of the transport of raw materials, power generation and heat consumption (WSA, 2014).

Nowadays, Brazil is the 8th steel producer of the globe, responsible for more than 33 million tonnes of crude steel yearly (IAB, 2013a). The country's steelmaking industry was responsible for the emission of 43 million tonnes of CO_2 in 2010, considering both fuel combustion derived (12,6%) and industrial process emissions (87,4%). Hence, the iron and steel industry is the largest industrial sector CO_2 emitter in Brazil (MCTIC, 2016).

However, the Brazilian steelmaking industry has a very particular characteristic, which is the use of charcoal to replace the mineral coal (coke) in the blast furnace reduction process: about 11% of the Brazilian steel production use charcoal instead of coke (Bajay, 2009). Hence, for the charcoal-based industrial facilities, the CO_2 emissions produced in the industrial process are compensated by the photosynthesis process that occurs in planted forests to obtain the wood that will be converted into charcoal, allowing the reduction of total emissions of the steelmaking process (EPE, 2009).

Many studies have been developed concerning the adoption of biomass in the steel production. In (Norgate and Langberg, 2009) the charcoal use in steelmaking was analyzed using a life cycle assessment methodology, indicating significant reduction on emissions, but also concluded the non-feasibility of charcoal on steel industry, demanding carbon taxes for its implementation. The study of (Rousset et al., 2011) is focused on verifying the best biomass and charcoal production process for steelmaking use of the fuel, a theme also studied in (Noumi, Blin and Rousset, 2014) highlighting the friability problems of charcoal use. The use of charcoal in the production of iron ore sinter is also analyzed by (Abreu et al., 2015). In (Norgate et al., 2012) the author

Abbreviations: Charcoal, Production route of integrated plants with charcoal; *Coke*, Production route of integrated plants with cokemaking; EAF, Production route of Electric Arc Furnaces (EAF); Indep, Production route of independent pig-iron producers; Integrated, Production route of integrated plants (charcoal + coke); Int_NoCoke, Production route of integrated plants without cokemaking; Pigiron, Associated with pig-iron production; *Steel*, Associated with steel production

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corroborates the CO_2 emissions reductions by adopting charcoal on the integrated steel production route, indicating values of 57% of greenhouse gases (GHG) emissions reduction on such steel routes. Also, (da Costa and Morais, 2006) describes the charcoal adoption in a blast furnace, looking to reduce emissions and costs given the increase of fossil fuel prices. The R&D projects for low carbon steel production was summarized in (Jahanshahi et al., 2015), highlighting that the biomass-derived chars have great potential in lowering the net CO_2 emissions of integrated (BF-BOF route) steel plants. The study of (Jahanshahi et al., 2013) presented the key findings for biomass supply and charcoal making in the steel industry, indicating Brazil as the only country where charcoal is a competitive fuel on steel industry. In addition, the study developed by (Chidumayo and Gumbo, 2013) provided important lessons of how to develop and maintain a sustainable charcoal production industry. Finally, (Mousa et al., 2016) reviewed the biomass applications on the steel industry, indicating the potential, benefits and limitations of GHG emissions reduction through the adoption of charcoal in substitution of coal on blast furnaces.

However, the source of the biomass used for the charcoal production is crucial to guarantee that no native forest is being used, (Sonter et al., 2015) verified that the use of native forests for charcoal production in Brazil increased from 2000 to 2007. In (Pikettya et al., 2009) the authors studied the availability of biomass from planted forests in Brazil to supply charcoal to the steel industry. In order to guarantee the sustainable charcoal use and develop its potential, in 2008 the country released the "Plano Siderurgia", a national plan based on three main pillars: (i) reduce the CO_2 emissions in the sector; (ii) avoid the deforestation of native forests; and (iii) enhance the competitiveness of the Brazilian iron and steel sector (CGEE, 2015).

As mentioned, the feasible production of steel via integrated route using charcoal is a differential of Brazil in relation to the standards of world steel industry (Jahanshahi et al., 2013). Nevertheless, in some cases, using charcoal in all integrated plants cannot be a feasible solution, because the use of biomass in very large blast furnaces can compromise the reduction processes due the friability of the charcoal (EPE, 2009). Since the granulometry is a basic factor in blast furnaces operation, the typical size of the coal must be three times the size of the iron ore in order to allow the maximum gas flow without compromising the fluidization of the reductor agent (Matos, 1976). Hence, if the blast furnace size increases the used charcoal size must be increased too, however, the charcoal presents difficulties in maintaining a uniform granulometry (Assis, 1982). According to (Chatterjee, 1994), the blast furnaces that use charcoal have a working volume of 110 m^3 and a working height of the furnace interior rarely exceeding 14 m, due to the poor mechanical resistance of the charcoal, with typical productions of 180 t per day.

The country's importance in global iron and steel production combined with the peculiarities of its charcoal use makes Brazil a unique case for the analysis of greenhouse emission gases in the steelmaking industry. Furthermore, during the recent efforts of the Brazilian government to formulate a strategy of implementation of the Nationally Determined Contributions (NDC) for the Paris Agreement of 2015, the iron and steel sector was considered a key sector given its major role in GHG emissions (MCTIC, 2017a). Therefore, this paper aims to verify the potential fuel savings and CO_2 emission reduction in the Brazilian steelmaking industry. The study evaluates both the adoption of biomass in the steel industry and the best available technologies (BAT) that could be implemented in Brazil, here so-called Structural and Intensity effects, respectively. The study calculates the impacts on the final energy consumption and GHG emissions. Meanwhile, the costs associated with the adoption of the BATs are also checked, with the objective of analyzing the potential of emission reduction using Marginal Abatement Cost Curves (MACC).

Actually, there are several studies estimating MACCs for industrial sectors in many different countries. These curves show the abatement effect, its potential and the cost effectiveness of the technologies under analysis. A study of energy reduction measures for various sectors of the industry was developed by (Worrell et al., 2000), while the aluminum industry was analyzed with more details in (Kermeli et al., 2014), and (Li and Zhua, 2014) developed MACCs for China's iron and steel industry.

Studies addressing the issue of increasing energy efficiency and mitigating CO_2 emissions in the iron and steel industry are also available in the literature. (Worrell et al., 2010) studied the impact of several energy measures for the iron and steel industry, detailing potential energy savings, greenhouse gases emissions and investment costs, in (Porzio et al., 2013) a decision support system for the steelmaking industry for the analysis of energy consumption reduction and CO_2 abatement is proposed. In (Gielen and Moriguchi, 2002), the authors studied the impacts of carbon taxes on the Japanese steel sector. In 1995, (Worrell, 1995) has studied the effect of advanced technologies of smelting on the Chinese steel production, and in (Worrell et al., 2001) analyzed the CO_2 emissions reduction of the US iron and steel industry. In (de Gouvello, 2010) a low carbon study for the country was made and the Brazilian industrial sector was analyzed, a low carbon scenario with the adoption of charcoal for pig-iron production was considered as GHG mitigation option. The Brazilian steel sector was also studied in (SEA-RJ, 2012), however changes in the current amount of charcoal usage were not considered. The potential abatement costs and associated polices for the country were analyzed in (Borba et al., 2012), the results indicated a potential emission reduction for the entire industrial sector of Brazil of 69.2 $MtCO_2$, from 2010 to 2030, given the adoption of fuel substitution using biomass.

As previously mentioned, the Brazilian iron and steel scale and singularities justify a country-focused study. There were a few studies considering the energy efficiency potential in the Brazilian steelmaking industry. (EPE, 2009) studied the energy use in the Brazilian iron and steel sector, decoupling the main production routes and detailing the processes characteristics; (Modesto and Bajay, 2010) studied the general potential of energy efficiency in the iron and steel industry in Brazil, identifying a total of 32% of possible reduction on the energy use in 2007. However, all papers are focused on a general overview of the steel industry. On the contrary, the research presented by this paper applies a bottom-up model, where every single process of the steelmaking industry was analyzed, and the composition of the processes followed the Brazilian iron steel industry characteristics (final energy consumption, percentage of production of each process, typical emissions, etc.), allowing the construction of MACCs with a higher accuracy. In addition, the main contribution and originality of this study lie in the fact that few studies focused on the use of charcoal in the steelmaking industry.

The steelmaking industry is an interesting and emblematic case. It is a global industry whose GHG emissions are usually high, corresponding to a major share of the industrial emissions. The same holds true to Brazil. However, there are several routes to produce steel, although the most economical one is also the most carbon-intensive, being based on the metallurgical coal. Interestingly, as this paper will show, most of the Best Available Technologies (BATs) that mitigate carbon emissions in the steelmaking process were developed to be applied in this coke-based route, given its global predominance. In Brazil, or even in emerging countries that might follow the Brazilian example, switching to charcoal based-routes reduce the available options related to BATs, but can abate carbon emissions simply because charcoal can derive from planted forests. In this sense, it is worth investigating which is the best approach: to follow the most consolidated route to produce steel (the most economic too), and introduce BATs on it; or to switch to a less competitive route with few available best technologies, but based on a renewable feedstock. By developing scenarios to Brazil, we are able to