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Assessment of Energy Efficiency Improvement and CO_2 Emission Reduction Potentials in the Iron and Steel Industry in China

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Abstract

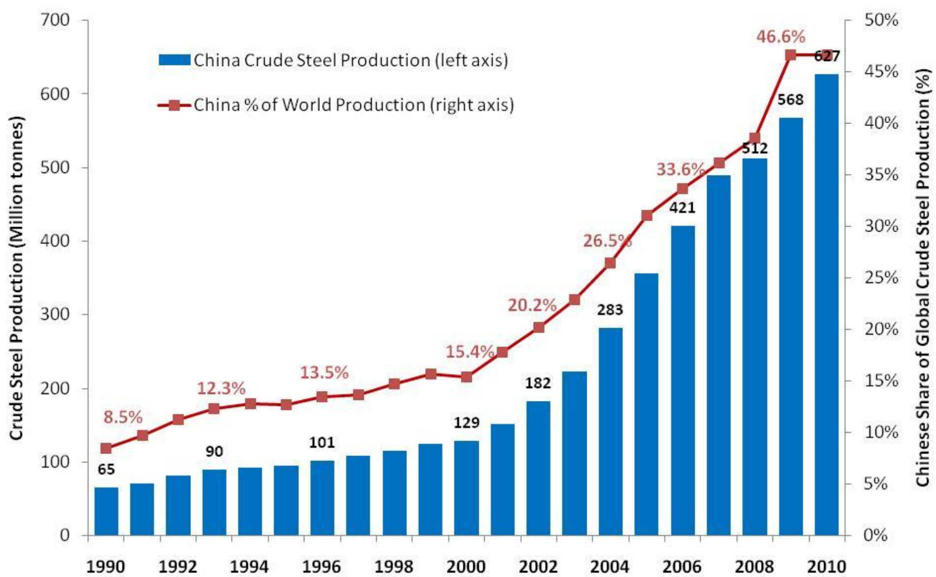
China's annual crude steel production in 2010 was 638.7 Mt accounting for nearly half of the world's annual crude steel production in the same year. Around 461 TWh of electricity and 14,872 PJ of fuel were consumed to produce this quantity of steel in 2010. We identified and analyzed 23 energy efficiency technologies and measures applicable to the processes in the iron and steel industry. The Conservation Supply Curve (CSC) used in this study is an analytical tool that captures both the engineering and the economic perspectives of energy conservation. Using a bottom-up electricity CSC model, the cumulative cost-effective electricity savings potential for the Chinese iron and steel industry for 2010-2030 is estimated to be 251 TWh, and the total technical electricity saving potential is 416 TWh. The CO_2 emissions reduction associated with cost-effective electricity savings is 139 Mt CO_2 and the CO_2 emission reduction associated with technical electricity saving potential is 237 Mt CO_2. The FCSC model for the iron and steel industry shows cumulative cost-effective fuel savings potential of 11,999 PJ, and the total technical fuel saving potential is 12,139. The CO_2 emissions reduction associated with cost-effective and technical fuel savings is 1,191 Mt CO_2 and 1,205 Mt CO_2, respectively. In addition, a sensitivity analysis with respect to the discount rate used is conducted to assess the effect of changes in this parameter on the results. The result of this study gives a comprehensive and easy to understand perspective to the Chinese iron and steel industry and policy makers about the energy efficiency potential and its associated cost.

Contents

1. Introduction

Production of iron and steel is an energy-intensive manufacturing process. In 2006, the iron and steel industry accounted for 13.6% and 1.4% of primary energy consumption in China and the U.S., respectively (Zhang et al., 2010).[1] The energy efficiency of steel production has a direct impact on overall energy consumption and related carbon dioxide (CO_2) emissions.

China is a developing country and is currently in the process of industrialization. The iron and steel industry, as a pillar industry for Chinese economic development, has grown rapidly along with the national economy. Starting in the 1990s, the industry development accelerated, with crude steel production in 1996 exceeding more than 100 million metric tonnes (Mt). Since then, steel production in China has continued to increase rapidly, and China has been the world's largest crude steel producer for 14 continuous years. The average annual growth rate of crude steel production was 18.5% between 2000 and 2009. China's steel production in 2010 consumed around 461 TWh of electricity and 14,872 PJ of fuel (NBS 2012), and represented 46.6% of the world steel production in that year (worldsteel, 2011) (see Figure 1).



Source: China Iron and Steel Industry Yearbook, various years; World Steel Association 2011

Figure 1: China's Crude Steel Production and Share of Global Production (1990-2010)

[1]Note that the 2009 China Energy Statistical Yearbook lists total primary energy use for Smelting and Pressing of Ferrous Metals as 447 million tons of coal equivalent (Mtce) in 2006, thereby comprising 17% of total primary energy use for that year (NBS, 2010a). This also includes the energy use by facilities that belong to steel enterprises but are not part of the steel production process such as residential houses of the enterprises. The results of this report, which is focused solely on the energy used for iron and steel production and is thus less comprehensive than the Yearbook category of Smelting and Pressing of Ferrous Metals, is that this industry accounted for 13.6% of total primary energy use in China in 2006.

The Chinese iron and steel industry has made much progress in reducing energy use, starting from energy saving on individual equipment and process energy conservation in 1980s to systematic energy conservation via process optimization in 1990. China's energy consumption per tonne of steel has declined significantly, especially since the 1990s, largely due to process restructuring and optimization.

During the ten years between 1990 and 2000, China's steel production almost doubled, but total energy consumption only increased 31%. From 2000 to 2005, steel production increased 174.2%, but energy consumption only increased 120% (Editorial Board of China Iron and Steel Industry Yearbook, various years). Specific energy consumption per tonne of steel in key medium and large - sized steel enterprises[2] dropped from 920 kgce/t steel in 2000 to 741 kgce/t steel in 2005 (Editorial Board of China Iron and Steel Industry Yearbook, various years).[3] Specific energy consumption per tonne of steel was reduced 19.5% from 2000 to 2005. Table 1 provides more detailed information on the reduction of energy intensity in the main processes of key steel enterprises.

Since 2000, energy conservation and emission reduction in China's steel industry has improved significantly (see Table 1 for key medium and large - sized steel enterprises). Academic advisors recommended that the steel industry explore the functions of steel product manufacturing, energy conversion, and utilization and treatment of waste resources (Yin, 2009). This focus leads to energy conservation and emission reduction in the steel industry. Meanwhile, China's national government is actively promoting the concept of a circular (or recycling) economy in the steel industry, encouraging widespread energy saving, emission reduction, increased steel scrap recycling rate, and resource conservation as necessary foundations of the circular economy. In addition, energy conservation is also seen as an effective way of reducing greenhouse gas emissions.

Under the guidance of the concept of "expanding the functions of steel manufacturing processes," promotion and application of energy-saving technologies has already become an important step for increasing energy efficiency and reducing energy consumption of steel enterprises. During this time, energy-conservation technologies adopted in China include: Coke Dry Quenching (CDQ), Top-pressure Recovery Turbine (TRT), recycling converter gas, recycling waste heat from converter steam, continuous casting, slab hot charging and hot delivery, Coal Moisture Control (CMC), and recycling waste heat from sintering. The penetration level of energy-conservation technologies in the steel industry has improved greatly in China, increasing energy conservation and emission reductions.

[2] These enterprises are members of the China Iron and Steel Association. A list of these companies can be found at here: http://www.chinaisa.org.cn/index.php?id=298

[3] The key steel enterprises do not represent the total Chinese iron and steel industry; thus the energy intensity of the whole iron and steel industry in China would be different from what is presented above for the key steel enterprises. Throughout this report all the data presented are for the whole Chinese iron and steel industry unless it is mentioned otherwise.

Table 1: Changes in Energy Intensity of Key Medium and Large-sized Chinese Steel Enterprises and in the Main Steel-Making Processes (2000-2008)

Year	Comprehensive Energy Consumption per tonne of steel (kgce/t)	Energy Intensity of Main Processes (kgce/t)[4]				
		Coking	Sintering	Iron-making	Basic Oxygen Furnace (BOF)	Electric Arc Furnace (EAF)
2000	920	160.20	68.90	466.07	28.88	265.59
2001	876	153.98	68.60	452.01	28.03	230.09
2002	815	150.32	67.07	455.13	24.01	228.94
2003	770	148.51	66.42	464.68	23.56	213.73
2004	761	142.21	66.38	466.20	26.57	209.89
2005	741	142.21	64.83	456.79	36.34	201.02
2006	645	123.11	55.61	433.08	9.09	/
2007	628	121.72	55.21	426.84	6.03	/
2008	630	119.97	55.49	427.72	5.74	/

Source: Editorial Board of China Iron and Steel Industry Yearbook, various years.

Notes: (1) Data in the table are from member companies of the China Iron and Steel Association.
(2) In the reported statistics, a primary energy conversion factor of 0.404 kgce/kWh was used for electricity during 1900-2005; and final energy conversion factor of 0.1228 kgce/kWh was used for electricity during 2006-2008. This is the primary reason for the large difference between the 2005 and 2006 data.
(3) Since 2006, the refining process of the BOF energy consumption is calculated separately.
(4) To convert units from kgce/t to GJ/t, multiply the values by 0.02931.

The study presented in this report is unique for China as it provides a detailed analysis of energy efficiency improvement opportunities for the entire iron and steel industry in China. In addition, compared with other international studies, the potential application of a larger number of energy-efficiency technologies is assessed. The objective of this study is to assess the potential for energy saving in the Chinese iron and steel industry using a technology-level, bottom-up approach and to estimate the cost associated with this potential. These results can guide policy makers in designing better sector-specific energy efficiency policy programs.

In this report, we first briefly presented an overview of the iron and steel industry in China. In the next section, the methodology will be presented. After that, we present the technologies and measures available for energy-efficiency improvement and greenhouse gas (GHG) emission reduction in the iron and steel industry, and conduct the technical and cost assessment for implementing those measures. We use the concept of a "Conservation Supply Curve (CSC)" (Meier 1982) to construct a bottom-up model in order to capture the cost-effective potential as well as the technical potential for energy efficiency improvement and CO_2 emission reduction. Finally, we present and discuss the results of the analysis.

[4] To convert kgce to GJ, multiply by 0.02931 and to convert kgce to Million Btu, multiply by 0.02778.

2. Methodology

2.1. Data Collection

The data collection in this report draws upon work done by Lawrence Berkeley National Laboratory (LBNL) on the assessment of energy efficiency and CO_2 emission reduction potentials of the iron and steel industry in the U.S. (Worrell et al. 1999; Xu et al. 2010; Worrell et al., 2010) and energy intensity calculation for Chinese and the U.S. steel industry (Hasanbeigi et al. 2011), as well as other references.

Because we could not obtain Chinese domestic technology information (e.g. energy saving, cost, etc.) for the energy efficiency measures/technologies, the analysis in this report is done based on international technologies only. International technologies are defined in our study as technologies that are manufactured outside of China. The data on the energy saving, cost, lifetime, and other details on each technology were obtained from these LBNL reports, which are based on case-studies around the world (Worrell et al. 1999 and 2010).

Many of the international energy-efficient technologies examined in LBNL publications and reports are used in this analysis because other studies on energy efficiency in the iron and steel industry do not provide consistent and comprehensive data on energy savings, cost, and lifetime of different technologies. Information on some of the technologies examined, however, was presented in other studies (e.g. APP 2010; EIPPCB 2008; NEDO 2008). Furthermore, the methodology used for this analysis, i.e. construction of the energy CSC and abatement cost curve, is also used by LBNL for the iron and steel industry in the U.S. (Sathaye et al. 2010, Worrell et al. 1999).

The year 2010 was defined as the base year since it was the last year for which the data was available from the Chinese statistics. The national level data for the production of different products for China's iron and steel industry was obtained from China Steel Yearbook 2011 (China Iron and Steel Industry Association, 2011) and from the China Energy Statistics Yearbook 2011 (NBS 2012). For the penetration rate of the energy efficient measures, a questionnaire was developed and sent to individual experts in China (see Appendix 2 for a copy of the questionnaire used). In addition, we obtained some data from the "National Key Energy Conservation Technologies Promotion Catalogue" published by National Development and Reform Council (NDRC, 2008, 2009, 2010) and from China's Energy research Institute's recent study for the analysis and evaluation of key industrial energy-efficient and emission reduction technologies (ERI 2011).

2.2. Conversion Factors and Assumptions

To convert electricity to primary energy, the conversion factor of 2.90 is used which is equivalent to China's national average net heat rate of fossil fuel-fired power generation of 0.333

kgce/kWh in 2010 plus national average transmission and distribution losses of around 6.5%[5] (SERC, 2011). The Lower Heating Value (LHV) of the fuel is used in the analysis. The 2010 monthly average exchange rate of 6.7 RMB/US$ is used to convert reported costs in Chinese Renminbi (RMB) to U.S. dollars (US$) (BOC 2010).

The carbon conversion factors for fuels used for calculating CO_2 emissions from energy consumption are taken from the 2006 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories (IPCC 2006). The emission factor for grid electricity is assumed to be 0.770 kg CO_2/kWh in 2010 and forecasted emission factors through 2030 were from the factors used in LBNL's China LEAP model (see Appendix 1) (Fridley et al. 2011). Since more than 98% of the fuel use in the Chinese iron and steel industry is coal and coke, the weighted average CO_2 emission factor of bituminous coal, coking coal, and coke consumed in the steel industry in 2010 is used as the CO_2 emission factor of fuel in the base year. The CO_2 emission factor of the fuel is assumed to be unchanged during the study period because coal and coke is assumed to be the primary source of fuel used in the Chinese iron and steel industry up to 2030.

The average unit price of electricity paid by the iron and steel industry in 2010 is used as the electricity price in the base year. The weighted average unit price of Bituminous coal, coking coal, and coke consumed in the steel industry in 2010 is used as the fuel price in the base year. Using energy prices in the base year and real electricity and fuel price escalation rates which are estimated based on Ni (2009), we calculated the energy prices in the future years during the study period. These prices are in constant dollars. Then, we used the same discount rate that we used to calculate the NPV of the future capital costs, to calculate the present value of the future energy prices in constant dollars in the base year. Finally, we calculated the discounted average unit price of electricity and coal used in electricity and fuel CSCs, respectively.

Future energy prices (i.e. prices in 2010-2030) govern the future benefits from energy cost savings and are treated the same as future capital and operation and maintenance (O&M) costs over the study period by discounting them to a present value using the same discount rate as applied to future capital and O&M costs. This consistent treatment represents the benefit cost decision from the industry perspective. If future energy prices are not treated the same as capital and O&M costs (i.e., not discounted to present value using the same discount rate), then the results could be misinterpreted as indicating that measures are cost effective to implement by overestimating the benefits (energy cost savings) relative to costs of measures.

[5] It should be noted that this value was the average net heat rate for those units larger than 6MW.

2.3. Energy Conservation Supply Curve Modeling

A bottom-up model based on the CSC concept was developed in order to estimate the cost effectiveness and technical potential for efficiency improvements and CO_2 emission reduction in China's iron and steel industry. The CSC approach, first introduced by Art Rosenfeld and his colleagues at LBNL, is an analytical tool that captures both the engineering and the economic perspectives of energy conservation. The curve shows the energy conservation potential as a function of the marginal Cost of Conserved Energy and has been used in various studies to assess energy efficiency potentials in different economic sectors and industries (Sathaye et al. 2010, Xu et al. 2010, 2011, Koomey et al. 1990, Levine and Meier 1999, Lutsey 2008, Hasanbeigi 2010a,b). McKinsey & Company (2008) also developed GHG abatement cost curves for different countries using the CSC concept. The CSC can be developed for a plant, a group of plants, an industry, or for the entire economic sector.

The work presented in this chapter is a unique study of China as it provides a detailed analysis of energy-efficiency improvement opportunities in the entire Chinese iron and steel industry.

The Cost of Conserved Energy (CCE) required for constructing the CSC can be calculated as shown in Equation 1:

$$\text{CCE} = \frac{\sum_{n=1}^{N} \frac{(ACC+\Delta\, AO\&M)_n}{(1+d)^n}}{\sum_{n=1}^{N}(Annual\ Energy\ Saving)_n} = \frac{\text{NPV (Annual Costs)}}{\text{Sum (Annual Energy Saving)}} \qquad \text{(Equation 1)}$$

Where:
CCE = Cost of Conserved Energy
ACC = Annualized Capital Costs
Δ AO&M = Change in Annual Operations and Maintenance Cost
n= year
N = time horizon of the analysis period
d = discount rate

The annualized capital cost can be calculated from Equation 2:

$$\text{Annualized capital cost} = \text{Capital Cost}^*(d/\ (1-(1+d)^{-n}) \qquad \text{(Equation 2)}$$

Where:
d = discount rate
n = lifetime of the energy efficiency measure

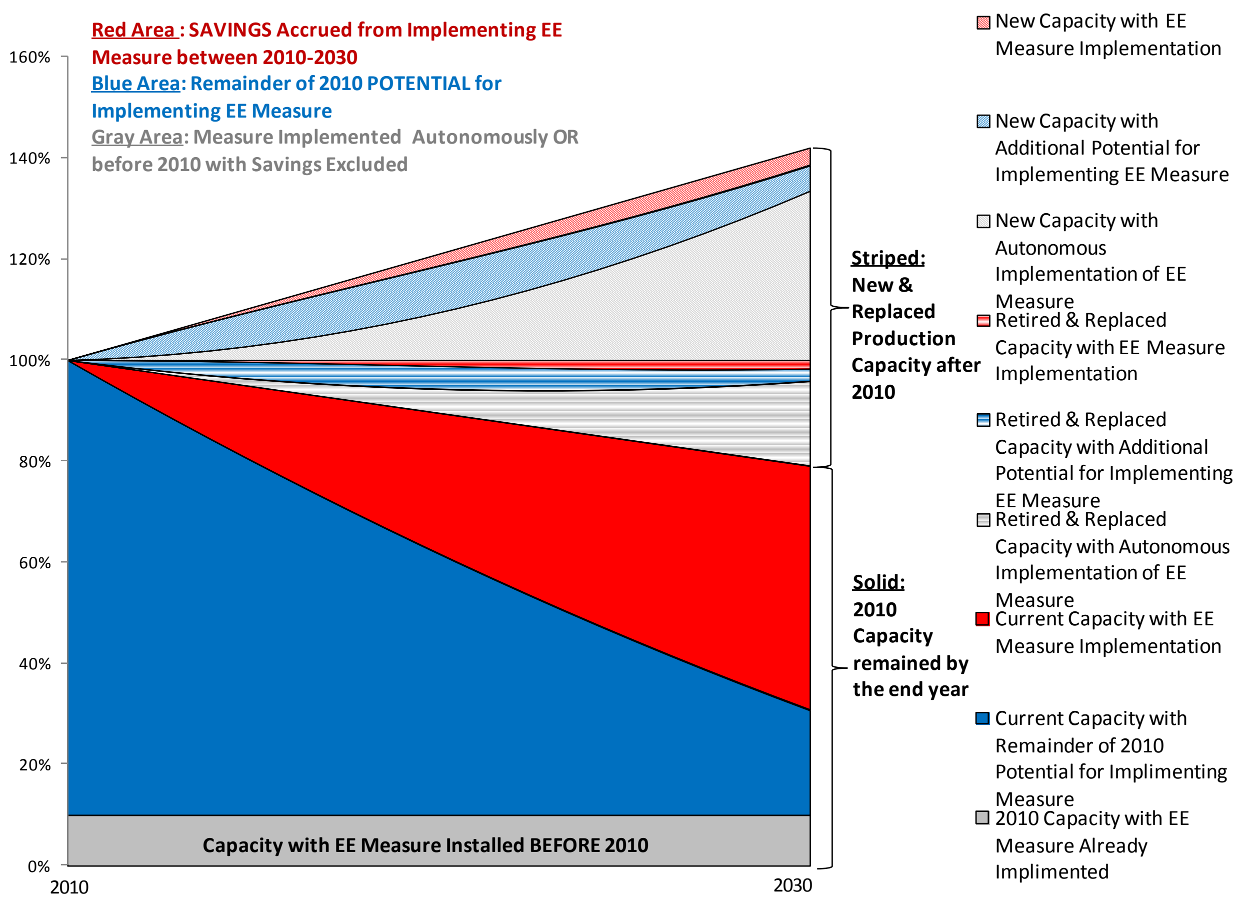
After calculating the Cost of Conserved Energy for all energy-efficiency measures separately, the measures were ranked in ascending order of their Cost of Conserved Energy to construct the Energy CSC, and measures were applied in cascading fashion to avoid "double counting" of savings between measures. In an Energy CSC, an energy price line is determined by the methodology described above in "conversion factors and assumptions". All measures that fall below the energy price line are considered "cost-effective". Furthermore, the CSC can show us the total technical potential for electricity or fuel savings accumulated from all the applicable measures. On the curve, the width of each measure (plotted on the x-axis) represents the energy saved by that measure in a year or during the period for which the analysis is conducted. The height (plotted on the y-axis) shows the measure's CCE calculated as explained above.

The methodology used for the analysis consists of five main steps as follows:

1. Establish 2010 as the base year for energy, material use, and production in the iron and steel industry. The base year is also used to calculate the costs in constant base year dollar. The study period for which the CSC was developed is 2010-2030. Thus, the implementation of the measure starts in 2010. This is different from some other studies such Xu (2010) where the application of energy efficiency technologies and the cost-effectiveness is assessed only for the base year.
2. Develop a list of commercially available energy-efficiency technologies and measures in the iron and steel industry to include in the construction of the conservation supply curves. We assumed that the energy efficiency measures are mutually exclusive and there is no interaction between them. Initially 64 energy efficiency technologies were listed in our questionnaire, but we could only get the information on penetration rate for 23 technologies. Thus, these 23 energy efficiency measures/technologies are used in this study based on their applicability to the Chinese iron and steel industry as well as the significant energy saving that can be achieved by the implementation of them.
3. Determine the potential application of energy-efficiency technologies and measures in the Chinese iron and steel industry in the base year based on information collected from several sources. We assumed 70% of the potential for energy efficiency measures will be realized by the end of 2030 (3.5% per year) (except for a two measures, injection of natural gas in blast furnace (BF) and injection of coke oven gas in BF, which were treated differently), with a linear deployment rate assumed between the start year (2010) and end year (2030).
4. Obtain the annual forecast data for steel demand up to 2030. The adoption rate explained in step 3 was based on the base year's production capacity. However, there will be new capacity installed between 2010 and 2030 to meet increased demand. Additionally, there will be plant retirements in the existing capacity that will be replaced with new capacity. To define the potential application of the measures to the new production capacity, we used the "new capacity with EE implementation" indicator. By defining this indicator, we take into consideration how much of the new capacity will have already implemented the energy efficiency measures from the start and how much potential will still exist in each subsequent year. We apply the same adoption assumptions to the retired and replaced capacity as we do to the new capacity.
5. Construct an Electricity Conservation Supply Curve (ECSC) and a Fuel Conservation Supply Curve (FCSC) separately in order to capture the accumulated cost-effectiveness and total technical potential for electricity and fuel efficiency improvements in the iron and steel industry from 2010 to 2030. For this purpose, the Cost of Conserved Electricity (CCE) and Cost of Conserved Fuel (CCF) were calculated separately for respective technologies in order to construct the CSCs. After calculating the CCE or CCF for all energy-efficiency measures,

rank the measures in ascending order of CCE or CCF to construct an ECSC and a FCSC, respectively. Two separate curves for electricity and fuel are constructed because the cost-effectiveness of energy-efficiency measures is highly dependent on the price of energy. Since average electricity and fuel prices differ between industries and because many technologies save either solely electricity or fuel, it is appropriate to separate electricity and fuel saving measures. Hence, the ECSC with discounted average unit price of electricity plots technologies that primarily save electrical energy while the FCSC with discounted average unit price of fuel plots technologies that primarily save fuel. Some measures save both fuel and electricity but only appears in the curve for which savings are dominant (ECSC versus FCSC).

An important aspect of the CSCs is the methodology that was used to determine how energy efficiency measures are implemented. An illustrative graph is used below to explain the underlying basis for the implementation of each energy efficiency measures in the model (Figure 2).



Note: This graph is only for illustrative purposes

Figure 2. Illustration of Methodology for Determining Implementation of Energy Efficiency Measures from 2010 to 2030

Based on data on actual penetration rate of energy efficiency measures in the base year (i.e. 2010), we can calculate the remaining potential for adoption of efficiency measures in the existing capacity in the base year. We first estimate how much of the existing capacity should be retired and replaced with new capacity based on historic capacity expansions and the assumption that steel plants last 30 years (IEA 2011). This is shown in the figure as "Retired and Replacement". For the remaining existing potential we assumed 70% adoption will be reached by 2030 (3.5% per year) for almost all measures. We developed a linear line which serves as the slope for the new implementation of the measure in each year between 2010 and 2030. We can then calculate the proportion of current capacity where savings are achieved through the implementation of the efficiency measure between 2010 and 2030 (solid red area in Figure 2).

In addition, industrial production capacity may grow between 2010 and 2030. To determine the implementation potential of efficiency measures in the new additional capacity, we did the following. First, we used estimated production capacity growth from (Fridley et al. 2011) and assumed that a certain proportion of the new capacity will adopt the efficiency measures autonomously each year (4% per year between 2010 and 2030) as a result of the installation of new efficient technology in the new stock (gray angular striped area in Figure 2**Error! Reference source not found.**). Since the autonomous implementation of the measure in some of the new capacity will occur regardless of new policies, the savings potential of the autonomous implementation is excluded from the supply curves calculation. Second, the new capacity with additional potential for implementing the efficiency measures (not captured in autonomous improvement) is determined for each year (blue angular striped area in Figure 2). We assumed that a certain portion of the new capacity with additional potential for implementing the efficiency measures adopts the measures each year (2% per year between 2010 and 2030) (the red angular striped area in Figure 2). We treat the *retired and replacement* capacity the same as new capacity expansions by assuming the same rates for autonomous adoption of energy efficiency measures and adoption rates within the additional potential for implementing the efficiency measures (the horizontal striped area in Figure 2). Because the *new capacity* and *retired* and *replaced* capacity are both calculated as the product of growth rates and the adoption rates, the resulting wedges are not always straight lines (e.g., gray stripped areas – both horizontal and angular). To sum up, the red solid and red stripped areas in Figure 2 is the total source of energy saving potentials captured on the supply curves.

In forecasted years when the demand for steel declines either relative to the previous year, which is the case for the Chinese steel demand forecast after 2018, we assumed that *new capacity* added after 2010 remains in production. Thus, we assumed that reduced demand results in a reduced production at inefficient plants. However, we first estimated energy efficiency adoptions in the existing capacity regardless of reduced demand. Therefore, if the demand decline between 2010 and 2030 is large enough, the entire inefficient capacity can reach the decommissioning or zero production point within this period. This results in saturated adoption in the remaining existing capacity and no additional adoptions are possible since the entire existing capacity has either adopted the measures or been decommissioned by the saturation year. This extreme case does not happened in this analysis given the demand forecast for the Chinese domestic use does not fall by large quantity during the study period. This represents one approach to deal with the sharp decreased cement demand in the future. Another case in the opposite direction is that steel production never falls despite domestic demand reductions and instead excess production is exported resulting in the same energy consumption, emissions, and energy efficiency adoption potential as would be the case if demand kept rising. Because of the transportation costs, exporting steel is not a highly profitable trade and Chinese companies are not exporting a high volume of steel either compared to the total production. However, a large demand reduction could put considerable downward pricing pressure on the steel industry and could result in significant exports in the future. Another case could be the export of old yet not retired equipment to another country when Chinese domestic demands fall considerably and exporting steel would not be attractive. We have no way of modeling exported equipment and therefore made a conservative assumption that inefficient capacity will no longer be available within China to adopt energy conservation measures.

Although the CSC model developed is a good screening tool for evaluating the potentials of energy-efficiency measures, the actual energy savings potential and cost of each energy-efficiency measure and technology may vary and depend on various conditions such as raw material quality (e.g. moisture content of raw materials, hardness of the limestone, etc.), technology provider, production capacity, size of the kiln, fineness of the final product and byproducts, time of the analysis, and other factors. Moreover, it should be noted that some energy efficiency measures also provide additional productivity and environmental benefits which are difficult and sometimes impossible to quantify. However, including quantified estimates of other benefits could significantly reduce the CCE for the energy-efficiency measures (Worrell et al., 2003; Lung et al., 2005).

2.4. Different Approaches for Developing Conservation Supply Curves

It should be noted that there are different approaches for developing energy conservation supply curves and CO_2 abatement cost curves. These approaches may use different mathematical formulae as well as time horizons for constructing the energy conservation supply curve. The method used for the development of the curve can significantly influence the results and the interpretation of them (Fleiter et al. 2009). The CSC approach we used in this study for the Chinese iron and steel industry is presented above. In this approach we calculated the cost of conserved energy by dividing the net present value (NPV) of annual costs (in US$) over the study period (2010-2030) by the simple sum of annual energy saving (in TWh or PJ) over the same period. We did not discount the energy saving values. Then, we presented the calculated cost of conserved energy on the CSC along with the cumulative energy saving over the same period. In addition, we projected the energy price in the future years up to 2030 and then discounted the forecasted energy price to the present value (2010 value). After that we calculated the average of these discounted energy prices to come with a single number used on the supply curve. Finally, we compared the cost of conserved energy with the discounted average energy price on the supply curves.

In some other studies such as McKinsey&Company (2009a), in addition to discounting the cash-flow of the annual costs, they also discounted the future annual energy savings to the present value and then sum these discounted present values to calculate the total energy saving in the present value over the time period. This is different from what we did in our study. The reason that we did not discount the energy saving is that energy savings in the future years are physical values presented in energy units (TWh or PJ). We believe that only monetary values should be discounted to represent the time value of the money, but the physical values (like energy saving) should not be discounted. Discounting the physical values will be misleading, as it will not represent the actual magnitude of the energy saving potential (in TWh or PJ) that can be achieved in the future.

The other approach commonly used in the construction of a CSC is to develop the curve only for one year (usually the base year). In this method, the cost of conserved energy is calculated by dividing the annual cost in the base year, which is the sum of annualized capital cost and the annual change in the O&M costs, by the annual energy saving in the base year. This approach is used in various studies such as Worrell et al. (1999) and Hasanbeigi et al. (2010c). Since this approach only shows the energy saving potential in the base year, the magnitude of saving shown on the supply curve is much lower than the cumulative, multi-year CSC shown on the supply curve developed using the methodology in our study. To sum up, when looking at a CSC and trying to interpret the results, one should pay attention to the method and formulae used in the development of the curve in addition to the assumptions used such as the discount rate, energy prices, period of the analysis, cost of technologies and their energy saving, etc. To make this important point clearer Hasanbeigi et al. (2012) gives an illustrative example with the detailed explanation on single-year CCE Vs. discounted CCE over time horizon.

2.5. Discount Rate

In this study, a real discount rate of 15% was assumed for the analysis. However, it should be noted that the choice of the discount rate depends on the purpose and approach of the analysis (prescriptive versus descriptive) used. A prescriptive approach (also known as social perspective) uses lower discount rates (4% to 10%), especially for long-term issues like climate change or public sector projects (Worrell et al. 2004). Low discount rates have the advantage of treating future generations more equally to current generations; thus may less favor the relatively certain, near-term effects over more uncertain, long-term effects (NEPO/DANCED, 1998).

A descriptive approach (or private-sector or industry perspective), however, uses relatively high discount rates between 10% and 30% in order to reflect the existence of barriers to energy efficiency investments (Worrell et al. 2004). These barriers include perceived risk, lack of information, management concerns about production and other issues, capital constraints, opportunity cost, and preference for short payback periods and high internal rates of return (Bernstein, et al. 2007 and Worrell, et al. 1999). Hence, the 15% discount rate used for these analyses is close to the higher end of discount rates from a social perspective and the lower end of the discount rates from private-sector or industry perspective.

Other industrial sector analyses use varying real discount rates. Carlos (2006) used a range of 10% to 16% discount rate in the financial analysis for cogeneration projects in Thailand. Garcia et al. (2007) used three discount rates of 12%, 15%, and 22% in three different investment scenarios for high efficiency motors in Brazil. Sathaye et al. (2010) used the discount rates of 10%, 20%, and 30% for different scenarios in their bottom-up modeling analysis for the U.S. iron and steel industry. McKinsey & Company used a 7% social discount rate for developing Conservation Supply Curves and GHG abatement cost curve for the US (McKinsey & Company, 2007 and 2009a) and a 4% social discount rate for developing a GHG abatement cost curve for China (McKinsey & Company, 2009b). ICF developed an abatement cost curve for the iron and steel industry in Brazil and Mexico in 2015 using a 10% discount rate (ICF International, 2009a, b). In the Asia Least-cost Greenhouse Gas Abatement Strategy (ALGAS) project, a 10% real discount rate is assumed for the calculation of GHG emissions abatement scenarios for various economic sectors including industry in Thailand (ADB/GEF, 1998).

3. Technologies and Measures to Reduce Energy and CO_2 Emissions for the Iron and steel Industry

Initially, 64 energy efficiency technologies were listed in our questionnaire, but we could only get the information on penetration rate for 23 technologies. Thus, these 23 energy efficiency measures/technologies are used in this study based on their applicability to the Chinese iron and steel industry and were used in the development of the conservation supply curves. The descriptions of these 23 measures can be found at Worrell et al. (2010). Table 2 presents data related to the production capacity in each step of the iron and steel production process in China. It also presents the energy savings, capital costs, and change in annual operation and maintenance (O&M) cost, and potential application share for each energy-efficiency technology and measure when applied to China’s iron and steel industry.

Table 2. Energy Savings and Costs for Energy-Efficient Technologies and Measures Applied to the Iron and steel Industry

No.	Technology/Measure***	Sinter production capacity in base year to which the measure is applied (Mt/year)	Typical Fuel savings (GJ/t-Sinter)	Typical Electricity savings (kWh/t-Sinter)	Typical Capital cost (2010 US$/t-Sinter)	Typical Change in annual O&M cost (2010 US$/t-Sinter)**	Typical lifetime of the technology (year)	Share of Sinter production capacity in base year (2010) to which measure is applicable (%) *
	Sintering							
1	Heat recovery from sinter cooler	688.22	0.52		4.1	-	10	90%
2	Increasing bed depth	688.22	0.01	0.06	0.0	-	10	0%
No.	**Technology/Measure**	**Coke production capacity in base year to which the measure is applied (Mt/year)**	**Fuel savings (GJ/t-Coke)**	**Electricity savings (kWh/t-Coke)**	**Capital cost (2010 US$/t-Coke)**	**Change in annual O&M cost (2010 US$/t-Coke)**	**Typical lifetime of the technology (year)**	**Share of Coke production capacity in base year (2010) to which measure is applicable (%) ***
	Coke Making *(within the steel industry)*							
3	Coal moisture control	123.36	0.17		71.3	-	10	95%
4	Coke dry quenching (CDQ)	123.36	1.41		85.2	0.7	18	45%
No.	**Technology/Measure**	**Pig Iron production capacity in base year to which the measure is applied (Mt/year)**	**Fuel savings (GJ/t- Pig Iron)**	**Electricity savings (kWh/t- Pig Iron)**	**Capital cost (2010 US$/t-Pig Iron)**	**Change in annual O&M cost (2010 US$/t-Pig Iron)**	**Typical lifetime of the technology (year)**	**Share of Pig Iron production capacity in base year (2010) to which measure is applicable (%) ***
	Iron Making – Blast Furnace							
5	Injection of pulverized coal in BF to 130 kg/t hot metal	559.72	0.77		8.7	-2.6	20	5%
6	Injection of natural gas in BF	559.72	0.37		5.9	-2.6	20	100%
7	Injection of coke oven gas in BF	559.72	0.36	18.50	5.9	-2.6	20	100%
8	Top-pressure recovery turbines (TRT)	559.72		46.00	26.7	-	15	17%
9	Recovery of blast furnace gas	559.72	0.04		0.4	-	15	94%
No.	**Technology/Measure**	**BOF crude steel production capacity in base year to which the measure is applied (Mt/year)**	**Fuel savings (GJ/t- BOF crude)**	**Electricity savings (kWh/t-BOF crude)**	**Capital cost (2010 US$/t-BOF crude)**	**Change in annual O&M cost (2010 US$/t-BOF crude)**	**Typical lifetime of the technology (year)**	**Share of BOF crude steel production capacity in base year (2010) to which measure is applicable (%) ***
	Steelmaking – basic oxygen furnace (BOF)							
10	Recovery of BOF gas and sensible heat	572.38	0.73		35.2	-	10	70%

No.	Technology/Measure	EAF crude steel production capacity in base year to which the measure is applied (Mt/year)	Fuel savings (GJ/t- EAF crude)	Electricity savings (kWh/t- EAF crude)	Capital cost (2010 US$/t- EAF crude)	Change in annual O&M cost (2010 US$/t- EAF crude)	Typical lifetime of the technology (year)	Share of EAF crude steel production capacity in base year (2010) to which measure is applicable (%) *
	Steelmaking – EAF							
11	Scrap preheating	66.31		61.00	7.6	-3.93	30	0%
No.	**Technology/Measure**	**Total crude steel production capacity in base year to which the measure is applied (Mt/year)**	**Fuel savings (GJ/t- Total crude)**	**Electricity savings (kWh/t- Total crude)**	**Capital cost (2010 US$/t- Total crude)**	**Change in annual O&M cost (2010 US$/t- Total crude)**	**Typical lifetime of the technology (year)**	**Share of Total crude steel production capacity in base year (2010) to which measure is applicable (%) ***
	Casting and Refining							
12	Integrated casting and rolling (Strip casting)	638.70	0.05	42.00	255.5	-27.37	20	80%
No.	**Technology/Measure**	**Hot rolled finished (HRF) steel production capacity in base year to which the measure is applied (Mt/year)**	**Fuel savings (GJ/t- HRF steel)**	**Electricity savings (kWh/t- HRF steel)**	**Capital cost (2010 US$/t- HRF steel)**	**Change in annual O&M cost (2010 US$/t- HRF steel)**	**Typical lifetime of the technology (year)**	**Share of HRF steel production capacity in base year (2010) to which measure is applicable (%) ***
	Hot Rolling							
13	Recuperative or regenerative burner	649.63	0.70		4.3	-	10	70%
14	Process control in hot strip mill	649.63	0.30		1.3	-	10	0%
15	Waste heat recovery from cooling water	649.63	0.04	-0.17**	1.1	0.1	15	80%
No.	**Technology/Measure**	**Cold rolled finished (CRF) steel production capacity in base year to which the measure is applied (Mt/year)**	**Fuel savings (GJ/t- CRF steel)**	**Electricity savings (kWh/t- CRF steel)**	**Capital cost (2010 US$/t- CRF steel)**	**Change in annual O&M cost (2010 US$/t- CRF steel)**	**Typical lifetime of the technology (year)**	**Share of CRF steel production capacity in base year (2010) to which measure is applicable (%) ***
	Cold Rolling							
16	Heat recovery on the annealing line	112.28	0.30	3.00	4.0	-	10	45%
17	Automated monitoring and targeting systems	112.28		60.0	1.8	-	10	45%
No.	**Technology/Measure**	**Total crude steel production capacity in base year to which the measure is applied (Mt/year)**	**Fuel savings (GJ/t- Total crude)**	**Electricity savings (kWh/t- Total crude)**	**Capital Cost (2010 US$/t- Total crude)**	**Change in annual O&M cost (2010 US$/t- Total crude)**	**Typical lifetime of the technology (year)**	**Share of Total crude steel production capacity in base year (2010) to which measure is applicable (%) ***
	General measures							
18	Preventative maintenance in integrated steel mills	638.70	0.43	5.56	0.01	0.03	20	60%

No.	Technology/Measure	Total crude steel production capacity in base year to which the measure is applied (Mt/year)	Fuel savings (GJ/t- Total crude)	Electricity savings (kWh/t- Total crude)	Capital Cost (2010 US$/t- Total crude)	Change in annual O&M cost (2010 US$/t- Total crude)	Typical lifetime of the technology (year)	Share of Total crude steel production capacity in base year (2010) to which measure is applicable (%) *
19	Preventative maintenance in EAF plants	638.70	0.09	13.89	0.01	0.03	20	60%
20	Energy monitoring and management systems in integrated steel mills	638.70	0.11	2.87	0.2	-	10	85%
21	Energy monitoring and management systems in EAF plants	638.70	0.02	2.87	0.2	-	10	85%
22	Variable speed drives for flue gas control, pumps, fans in integrated steel mills	638.70		11.11	2.2	-	10	85%
23	Cogeneration for the use of untapped coke oven gas, blast furnace gas, and basic oxygen furnace-gas in integrated steel mills	638.70	0.03	97.22	20.2	-	20	50%

HRF steel: Hot rolled finished steel; CRF steel: Cold rolled finished steel

* The share of production capacity in base year (2010) to which the measure is **applicable** is different than the share of production capacity in the base year to which the measure is **applied**. The method for determining the application rates of the measures are described in detail in the methodology section with Figure 2 as an illustration.

** The negative value for electricity saving indicates that although the application of this measure saves fuel, it will increase electricity consumption. However, it should be noted that the total primary energy savings of these measures is positive.

*** The descriptions of these 23 measures can be found at Worrell et al. (2010).

4. Results and Discussions

Based on the methodology explained above and the information from Table 2, the FCSC and ECSC were constructed separately to estimate the cost-effective and total technical potential for electricity and fuel efficiency improvement in the Chinese iron and steel industry from 2010 to 2030. In addition, the CO_2 emission reduction potential from implementing efficiency measures was also calculated. Out of 23 energy-efficiency measures that were included in the analysis, 20 measures were applicable to the iron and steel industry in China (the other 3 measures already have 100% adoption rate in China), 15 of which are fuel-saving measures that are included in FCSC and 5 of which are electricity-saving measures used to derive the ECSC.

However, it should be noted that there are some technologies such as preventative maintenance in integrated and EAF steel mills, energy monitoring and management systems in integrated and EAF steel mills, cogeneration, heat recovery on the annealing line, waste heat recovery from cooling water, flameless oxy-fuel burners, integrated casting and rolling (Strip casting), and injection of natural gas in BF that either save both electricity and fuels, or increase electricity consumption as a result of saving fuel. These technologies with fuel savings accounting for a larger portion of their total primary energy savings are included in the FCSC with exception for cogeneration and integrated casting and rolling for which the electricity saving has a larger share of total primary energy saving; thus these two measures are included in ECSC.

4.1. Fuel Conservation Supply Curve for the Iron and steel Industry

Fifteen energy-efficiency measures were used to construct the FCSC. Figure 3 shows that fourteen energy-efficiency measures fall below the discounted average unit price of fuel in the iron and steel industry from 2010 to 2030 (3.4US$/GJ), indicating that the CCF is less than the discounted average unit price of fuel for these measures. In other words, the cost of investing in these fourteen energy-efficiency measures to save one GJ of energy in the period of 2010 - 2030 is less than purchasing one GJ of fuel at the given price. The other one efficiency measure (grey area in Table 3) is technically applicable but it is not cost-effective; thus, its implementation may require financial incentives beyond energy savings alone.

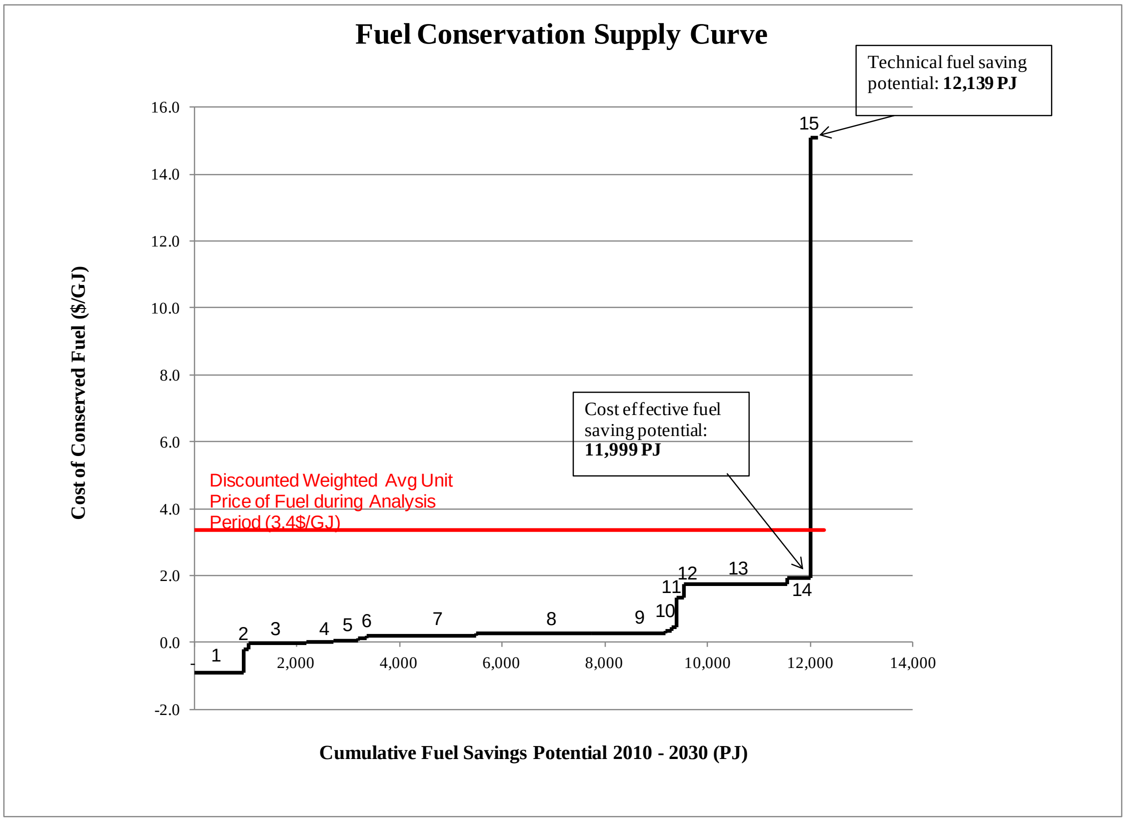


Figure 3. 2010-2030 FCSC for the Iron and steel industry in China

Table 3 presents the fuel efficiency measures applicable to the iron and steel industry ranked by their CCF. The fuel savings and CO_2 emission reduction achieved by each measure is also shown. Injection of natural gas in BF and injection of pulverized coal in BF to 130 kg/t hot metal are the two most cost-effective measures. The highest fuel saving during 2010-2030 is achieved by recuperative or regenerative burner in hot rolling followed by heat recovery from sinter cooler. Table 4 shows the cumulative cost-effective and the total technical potential for energy saving and CO_2 emission reduction from 2010 to 2030 as calculated by the model.

Table 3. Fuel Efficiency Measures for the Iron and steel industry in China Ranked by Cost of Conserved Fuel (CCF)

CCF Rank	Efficiency Measure***	Fuel Savings (PJ)	Cost of Conserved Fuel (US$/GJ-saved)	CO_2 Emission Reduction (Mton CO_2)
1	Injection of natural gas in BF	953	-0.87*	100
2	Injection of pulverized coal in BF to 130 kg/t hot metal	82	-0.20*	9
3	Preventative maintenance in integrated steel mills*	1,124	0.01	110
4	Preventative maintenance in EAF plants*	541	0.02	39
5	Energy monitoring and management systems in integrated steel mills*	479	0.05	45
6	Energy monitoring and management systems in EAF plants*	169	0.15	12
7	Recuperative or regenerative burner	2,139	0.22	223
8	Heat recovery from sinter cooler	2,244	0.29	234

CCF Rank	Efficiency Measure***	Fuel Savings (PJ)	Cost of Conserved Fuel (US$/GJ-saved)	CO_2 Emission Reduction (Mton CO_2)
9	Injection of coke oven gas in BF*	1,425	0.30	122
10	Recovery of blast furnace gas	129	0.36	13
11	Heat recovery on the annealing line*	97	0.46	10
12	Waste heat recovery from cooling water*	137	1.35	15
13	Recovery of BOF gas and sensible heat	2,016	1.74	210
14	Coke dry quenching (CDQ)	463	1.95	48
15	Coal moisture control	140	15.12	15

* For this measure, primary energy saving was used to calculate CCF based on both the electricity and fuel savings. Since the share of fuel saving is more than that of electricity saving for this measure, this measure is included between fuel saving measures.
** O&M costs of this measure show a net decrease due to reduced coke purchase costs and reduced maintenance costs of existing coke batteries. This negative O&M cost results in a negative CCF when calculated over the study period (2010-2030).
*** The descriptions of these 15 measures can be found at Worrell et al. (2010).

Table 4. Cost-Effective and Total Technical Potential for Fuel Saving and CO_2 Emission Reduction in the Iron and steel Industry in China during 2010-2030

	Cumulative Fuel Saving Potential (PJ)		Cumulative Carbon Dioxide Emission Reduction ($MtCO_2$)	
	Cost-Effective	Technical	Cost-Effective	Technical
Cumulative saving potentials during 2010-2030	11,999	12,139	1,191	1,205

4.2. Electricity Conservation Supply Curve for the Iron and steel Industry

For the iron and steel industry, five energy-efficiency measures are included in the ECSC. Figure 4 and Table 5 show that four out of five energy-efficiency measures on ECSC fall below the discounted average unit price of electricity in studied plants during the period of 2010-2030 (25.3US$/ megawatt-hour, MWh). Therefore, the CCE for these four measures is less than the discounted average electricity price during the study period. In other words, these measures can be considered cost-effective as the cost of investing in these four energy-efficiency measures to save one MWh of electricity is less than purchasing one MWh of electricity at the discounted average 2010-2030 unit price of electricity.

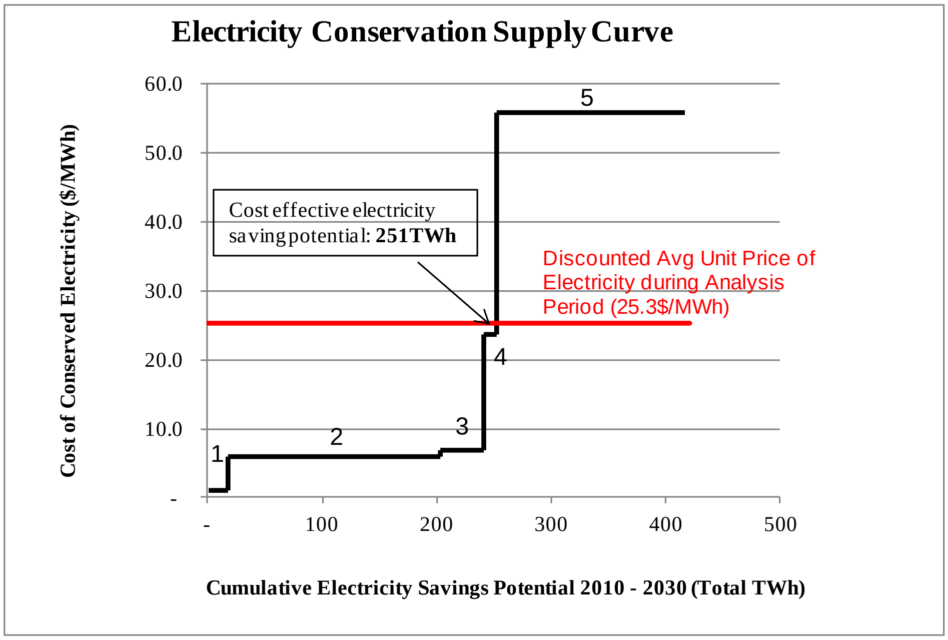


Figure 4. 2010-2030 ECSC for the Iron and steel Industry in China

Table 5. Electricity Efficiency Measures for the Iron and steel industry in China Ranked by Cost of Conserved Electricity (CCE)

CCE Rank	Efficiency Measure**	Electricity Savings (TWh)	Cost of Conserved Electricity (US$/MWh-saved)	Cumulative CO_2 Emission Reduction (Mton CO_2)
1	Automated monitoring and targeting systems	18	1.14	10
2	Cogeneration for the use of untapped coke oven gas, blast furnace gas, and basic oxygen furnace-gas in integrated steel mills*	185	6.11	103
3	Variable speed drives for flue gas control, pumps, fans in integrated steel mills	38	7.04	21
4	Top-pressure recovery turbines (TRT)	11	23.71	6
5	Integrated casting and rolling (Strip casting)*	165	56.04	98

* For this measure, the share of electricity saving is more than that of fuel saving; thus, this measure is included between electricity saving measures on ECSC. To convert fuel saving by this measure to electricity saving, the national average power generation efficiency is used.
**The descriptions of these 5 measures can be found at Worrell et al. (2010).

The two most cost-effective measures are automated monitoring and targeting systems and Cogeneration. The largest electricity saving potential is from Cogeneration (ranked 2 on the curve) followed by integrated casting and rolling (Strip casting) (ranked 5 on the curve). Table 6 shows the cumulative cost effective and the total technical potential for electricity saving and CO_2 emission reduction from 2010 to 2030.

Table 6. Cost-Effective and Total Technical Potential for Electricity Saving and CO2 Emission Reduction in the Iron and steel Industry in China during 2010-2030

	Cumulative Electricity Saving Potential (TWh)		Cumulative Carbon Dioxide Emission Reduction (MtCO2)	
	Cost-effective	Technical	Cost-effective	Technical
Cumulative saving potentials during 2010-2030	251	416	139	237

4.3. Sensitivity Analysis

In the previous sections, the cost-effective and technical energy-efficiency improvement potentials for the iron and steel industry in China were presented and discussed. Since the discount rate used in the analysis is among the parameters that play an important role in the analysis and results of energy-efficiency potentials, it is important and relevant to see how changes in this parameter can influence the cost effectiveness of the potentials. Hence, a discount rate sensitivity analysis was performed and the results are discussed below.

We conducted the sensitivity analysis for discount rates of 13% and 17% which are very close to the 15% discount rate used in the base case analysis. This was because some plants may use slightly different discount rate than 15% for their investment decision making. Thus, we assess the effect of the minor changes in the discount rate from the base case on the cost-effectiveness of savings. In addition, we conducted the sensitivity analysis for a low discount rate of 5% which represent more societal perspective to see how the cost-effectiveness will change by using a low societal discount rate. Finally, we used a 30% discount rate for the sensitivity analysis which is at the higher end of industry perspective for the discount rate (Table 7). Because of the various non-monetary barriers such as lack of information, uncertainty about energy efficiency technologies, lower priority, etc. industry often tend to use a higher discount rate which discourages energy efficiency investments. Conducting the sensitivity analysis using 30% discount rate, we assess the effect of high discount rate on the cost-effectiveness of savings.

Table 7. Sensitivity Analysis for the Cost-Effective Electricity and Fuel Saving Potentials and CO_2 Emission Reductions in Chinese Iron and steel Industry during 2010-2030 with Different Discount Rates Keeping Other Parameters Constant

Discount Rate (%)	Electricity		Fuel	
	Cost-effective saving (TWh)	Cost-effective CO_2 emission reduction ($MtCO_2$)	Cost-effective saving (PJ)	Cost-effective CO_2 emission reduction ($MtCO_2$)
d.r. = 5	416	237	11,999	1,191
d.r. = 13	251	139	11,999	1,191
d.r. = 15 *	251	139	11,999	1,191
d.r. = 17	241	133	11,999	1,191
d.r. = 30	241	133	11,999	1,191

*: The discount rate = 15% is the base scenario which is used in the main analysis presented in previous sections.

Table 7 shows how changes in the discount rate can affect the cost-effective energy-saving potentials and their associated CO_2 emission reduction potentials, keeping constant the other parameters (i.e. electricity and fuel prices, investment cost of the measures, and energy saving of the measures). It shows that, for this specific study, the reduction of the discount rate from 15% to 13% will not change the estimated cost-effective electricity savings. The cost-effective fuel savings will not change by changes in the discount rate in the range of 5 to 30% and it will remain equal to 11,999 PJ. The reason for this is that the fourteen cost-effective measures in Fuel CSC are by far cost-effective and the measure ranked fifteen is by far not cost-effective Changes in the discount rate in the range of 5 to 30% will not affect their cost effectiveness. The decrease in the discount rate from 15% to 5% increases the cost-effective electricity saving from 251 TWh to 416 TWh, whereas the increase in the discount rate from 15% to 17% and 30% decreases the cost-effective electricity saving from 251 TWh to 241 TWh.

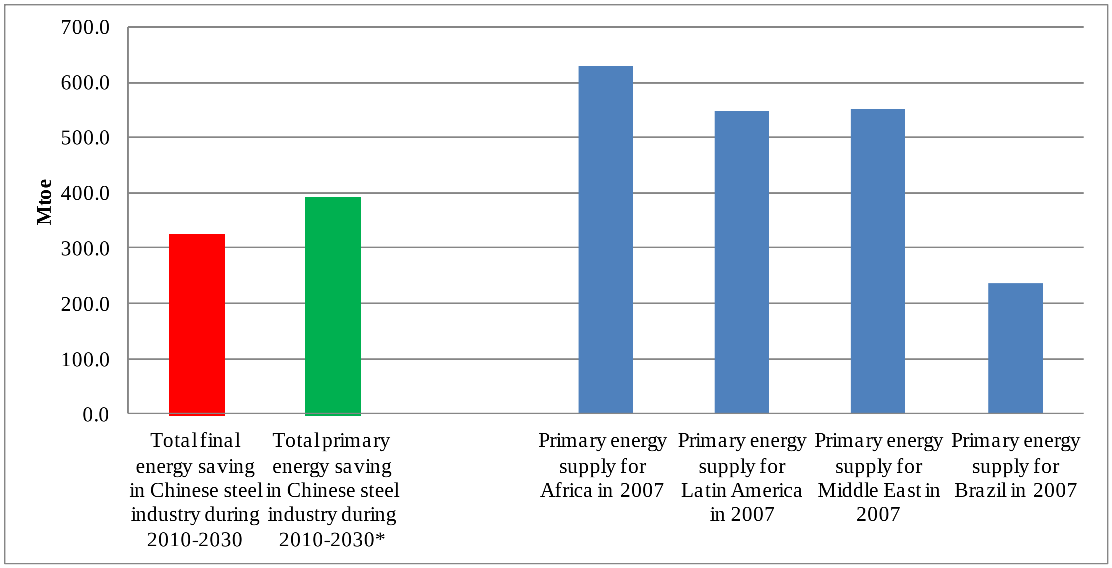
In general, it should be noted that variations in the discount rate may not change the cost-effectiveness of the measures. Measures that are cost-effective are measures that fall below the units price of energy (electricity or fuel) used in the CSCs. But the unit price of energy is also discounted using the same discount rate. The magnitude of the changes in the cost of conserved energy and the discounted unit price of energy resulting from changing the discount rate will define the change in the cost-effectiveness of the savings. The total technical energy saving and CO_2 emission potentials do not change with the variation of the discount rate.

5. Conclusions

The bottom-up Energy Conservation Supply Curves (i.e. ECSC and FCSC) were constructed for the Chinese iron and steel industry to estimate the savings potential and costs of energy-efficiency improvements by taking into account the costs and energy savings of different technologies.

We analyzed 23 energy efficiency technologies and measures for the iron and steel industry. Using a bottom-up CSC models, the cumulative cost-effective and technical electricity and fuel savings as well as the CO_2 emissions reduction potentials for the Chinese iron and steel industry for 2010-2030 are estimated. By comparison, the total technical primary[6] energy saving achieved by the implementation of the studied efficiency measures in the Chinese iron and steel industry over 20 years (2010-2030) is equal to around 72% of total primary energy supply of Latin America or the Middle East or around 168% of primary energy supply of Brazil in 2007 (IEA 2009). Figure 5 shows the comparison of the energy savings from the Chinese steel industry calculated in this study with the total primary energy supply of Latin America, the Middle East, Africa, and Brazil in 2007.

[6] The electricity savings during 2010-2030 is converted to primary energy using the 2010 China's average final to primary electricity conversion factor (2.90).



*: Mtoe: Million tonne of oil equivalent

Figure 5. Comparison of the calculated energy savings for the Chinese steel industry with the total primary energy supply of Latin America, the Middle East, Africa, and Brazil

When looking at CSCs and trying to interpret the results, one should pay attention to the method and formulas used in the development of the curves in addition to the assumptions used such as the discount rate, energy prices, period of the analysis, cost of technologies and their energy saving, etc. Finally, the approach used in this study and the model developed can be viewed as a screening tool for helping policymakers understand the savings potential of energy-efficiency measures and design appropriate policies to capture the identified savings. However, energy-saving potentials and the cost of energy-efficiency measures and technologies will vary according to country- and plant-specific conditions. This study shows that in China's case, an efficiency gap remains in the iron and steel industry as many of the identified cost-effective opportunities for energy efficiency improvement still have not been adopted. The persistence of this efficiency gap results from various obstacles to adoption and suggests that effective energy efficiency policies and programs are needed to realize cost-effective energy savings and emission reduction potential.

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Appendixes

Appendix 1. Time Dependent Key Model Inputs

Time Dependent Key Model Inputs	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Emissions Factors																					
CO2 Emission factor for grid electricity (tonne CO2/MWh)	0.770	0.746	0.723	0.700	0.676	0.653	0.638	0.624	0.609	0.594	0.580	0.565	0.550	0.535	0.520	0.505	0.492	0.478	0.465	0.451	0.438
CO2 Emission factor for fuel (tonne CO2/TJ)	94.60	94.600	94.600	94.600	94.600	94.600	94.600	94.600	94.600	94.600	94.600	94.600	94.600	94.600	94.600	94.600	94.600	94.600	94.600	94.600	94.600
Industry Product Capacity Growth Rate (Change compared to Base Year-2010)																					
Sintering		2%	4%	5%	7%	9%	11%	11%	12%	13%	11%	9%	9%	9%	10%	11%	9%	9%	9%	10%	6%
Coke Making		2%	4%	5%	7%	9%	11%	11%	12%	13%	11%	9%	9%	9%	10%	11%	9%	9%	9%	10%	6%
Iron Making – Blast Furnace		2%	4%	5%	7%	9%	11%	11%	12%	13%	11%	9%	9%	9%	10%	11%	9%	9%	9%	10%	6%
Steelmaking – basic oxygen furnace (BOF)		2%	4%	5%	7%	9%	11%	11%	12%	13%	11%	9%	9%	9%	10%	11%	9%	9%	9%	10%	6%
Steelmaking – EAF		2%	4%	15%	17%	19%	21%	31%	33%	34%	42%	40%	38%	49%	51%	52%	61%	60%	60%	62%	66%
Casting and Refining		2%	4%	6%	8%	10%	12%	13%	15%	16%	15%	13%	12%	14%	15%	16%	16%	16%	16%	17%	14%
Hot Rolling		2%	4%	6%	8%	10%	12%	13%	15%	16%	15%	13%	12%	14%	15%	16%	16%	16%	16%	17%	14%
Cold Rolling		2%	4%	6%	8%	10%	12%	13%	15%	16%	15%	13%	12%	14%	15%	16%	16%	16%	16%	17%	14%
		2%	4%	6%	8%	10%	12%	13%	15%	16%	15%	13%	12%	14%	15%	16%	16%	16%	16%	17%	14%

Source: Fridley et al. (2011)

Appendix 2. The questionnaire used to collect Chinese data

Dta of China's iron and steel industry

Year for which the national data in given below:	2010	Reference			
		#1	#2	#3	*Add Column as Necessary*
Pig Iron	**2010 (tonne)**				
Production					
Export					
Import					
Direct-reduced Iron	**2010 (tonne)**				
Production					
Export					
Import					
Iron making by smelting reduction	**2010 (tonne)**				
Production					
Crude steel	**2010 (tonne)**				
Integrated steel mills					
EAF plants					
Sub-total of BOF and EAF					
Other					
Total					
Steel mill finished products	**2010 (tonne)**				
Production					
Export					
Import					
Share of Hot Rolled steel products from total finished steel products					
Share of Cold Rolled steel products from total finished steel products					
Ingots, blooms, billets, and slabs	**2010 (tonne)**				
Export					
Import					
Coke	**2010 (tonne)**				
Production within iron and steel industry					
Import to iron and steel industry (from other sectors or other countries)					
Total					
Sinter	**2010 (tonne)**				
Production within iron and steel industry					
Export outside of iron and steel industry					
Import to iron and steel industry					
Lime	**2010 (tonne)**				
Production within iron and steel industry					
Export outside of iron and steel industry					
Import to iron and steel industry					
Oxygen	**2010 (Million m3 in gaseous form)**				
Production within iron and steel industry					
Export outside of iron and steel industry					
Import to iron and steel industry					

Energy Use data of China's iron and steel industry

	2010	Units	Heating Value	Heating Value Units	Reference #1	#2	#3	*Add Column as Necessary*
Fuel Comsumption:								
Bituminous coal/Raw coal (used as fuel)								
Coking coal (Clean coal)								
Other Clean coal								
Coke oven coke (purchased)								
Natural gas								
Fuel oil								
LPG								
other washed coal								
crude oil								
gasoline								
kerosene								
diesel								
other petroleum products								
Other (Please Specify)								
Add Row as Necessary								

	2010 Quantity	Units	Heating Value	Heating Value Units	Reference #1	#2	#3	*Add Column as Necessary*
Fuel used to Generate Electricity onsite:								
Bituminous coal (used as fuel)								
Other (Please Specify)								
Other (Please Specify)								
Add Row as Necessary								

	2010 Quantity	Units	Nominal Energy Price Esclation Rate	Real Energy Price Esclation Rate	References	
Energy Price:						
Electricity						
Bituminous coal/Raw coal (used as fuel)						
Coking coal (Clean coal)						
Other Clean coal						
Coke oven coke						
Natural gas						
Fuel oil						
LPG						
other washed coal						
Other (Please Specify)						
Add Row as Necessary						

China's Electricity Grid Efficency	2010
Conversion efficiency of primary energy to electric energy of China's grid including Transmission and Distribution line losses	

Adoption rate of energy efficiency technologies in Chinese steel industry

No.	Energy-Efficiency Measures / Technologies	Adoption rate in Chinese steel industry as % of total production for each process step in the base year
	Sintering	as % of Sinter production
1	Heat recovery from sinter cooler	
2	Reduction of air leakage	
3	Increasing bed depth	
4	Use of waste fuel in sinter plant	
5	Improve charging method	
6	Improve ignition oven efficiency	
	Coke Making	as % of Coke production
7	Coal moisture control	
8	Programmed heating in coke oven	
9	Variable speed drive on coke oven gas compressors	
10	Coke dry quenching (CDQ)	
11	Next generation coke making technology (SCOPE21) (emerging technology)	
	Iron Making – Blast Furnace	as % of Pig Iron production
12	Injection of pulverized coal in BF to 130 kg/t hot metal	
13	Injection of natural gas in BF	
14	Injection of oil in BF	
15	Injection of plastic waste in BF	
16	Injection of coke oven gas in BF	
17	Top-pressure recovery turbines (TRT)	
18	Recovery of blast furnace gas	
19	Improved blast furnace control	
20	Slag heat recovery (emerging technology)	
21	Preheating of fuel for hot blast stove	
22	Improvement of combustion in hot blast stove	
23	Improved hot blast stove control	

	Steelmaking – basic oxygen furnace (BOF)	**as % of BOF crude steel production**
24	Recovery of BOF gas and sensible heat	
25	Variable speed drive on ventilation fans	
26	Control system for oxygen supply to BOF process	
27	Programmed and efficient ladle heating	
	Steelmaking – EAF	**as % of EAF crude steel production**
28	Converting the furnace operation to ultra-high power (UHP) (Increasing the size of transformers)	
29	Adjustable speed drives (ASDs) on flue gas fans	
30	Oxy-fuel burners/lancing	
31	Post-combustion of flue gases	
32	Improving process control in EAF	
33	Refractories using engineered particles	
34	Direct current (DC) arc furnace	
35	Scrap preheating	
36	Plastic waste and used tire injection in EAF (emerging technology)	
37	Airtight operation (emerging technology)	
38	Bottom stirring/gas injection	
39	Contiarc Furnace (emerging technology)	
40	Comelt Furnace (emerging technology)	
	Casting and Refining	**as % of total crude steel production**
41	Integrated casting and rolling (Strip casting)	
42	Efficient Ladle preheating	
	Shaping	**as % of finished steel production**
43	Use of energy-efficient motors	
44	Installation of lubrication system	
	Hot Rolling	**as % of finished steel production**
45	Recuperative or regenerative burner	
46	Flameless oxyfuel burners	
47	Controlling oxygen levels and variable speed drives on combustion air fans	
48	Insulation of reheat furnaces	
49	Hot charging	
50	Process control in hot strip mill	
51	Heat recovery to the product	
52	Waste heat recovery from cooling water	
53	Walking beam furnace for reheating	
	Cold Rolling	**as % of finished steel production**
54	Continuous annealing	
55	Heat recovery on the annealing line	
56	Reduced steam use in the acid pickling line	
57	Automated monitoring and targeting systems	
	General measures	**as % of total crude steel production**
58	Preventative maintenance in integrated steel mills	
59	Preventative maintenance in EAF plants	
60	Energy monitoring and management systems in integrated steel mills	
61	Energy monitoring and management systems in EAF plants	
62	Variable speed drives for flue gas control, pumps, fans in integrated steel mills	
63	Variable speed drives for flue gas control, pumps, fans in EAF plants	
64	Cogeneration for the use of untapped coke oven gas, blast furnace gas, and basic oxygen furnace gas in integrated steel mills	