Sectoral Energy Report

The Iron and Steel Sector

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ESA^2 – Sectoral Energy Reports

The EU's ambitious energy and climate objectives require a coordinated approach by all involved stakeholders. While policy sets the legal framework, the decision for investments in the energy sector and the implementation of climate protection measures rests with a variety of actors (e.g. energy supplier, network operators, municipalities, industries, business and households) who have different economic preferences. Often individual decision makers lack sufficiently reliable information in advance to assess the ratio of costs and benefits of their own options and the effects of their decisions for the collective energy system and the environment. To enable sustainable decision support for all relevant decision makers in energy systems, instruments are needed which allow a dynamic system analysis, taking into account the interactions between political, technical and economic conditions and the behaviour of individual actors.

The Sectoral Energy Reports focus on the energy profiles of specific industry sectors and seek to identify action areas for ensuring competitiveness in a context of stringent climate change mitigation requirements and increased global market competition. The reports provide a knowledge base that goes beyond the specific sector in focus as new goals will have to be defined at the strategic level, requiring a broader system approach and involvement of multiple stakeholders. The Sectoral Energy Reports provide the broad contextualized background of the challenges being faced by industry sectors in Europe.

The Energy Systems Analysis Agency (ESA^2) builds on knowledge and experience of 14 European research groups/companies in the field of energy systems analysis. ESA^2 has its starting point in an innovation project developed within the Knowledge and Innovation Centre (KIC) InnoEnergy. KIC InnoEnergy is an initiative created under the leadership of the European Institute of Innovation and Technology (EIT) and aims to be the leading engine for innovation and entrepreneurship in sustainable energy.

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BF	Blast Furnace
BOF	Basic Oxygen Furnace
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CIS	Commonwealth of Independent States
DR	Direct Reduction
EAF	Electric Arc Furnace
ESA[2]	Energy Systems Analysis Agency
ETS	Emission Trading Scheme
EU	European Union
GDP	Gross Domestic Product
GHG	Greenhouse Gas
JI	Joint Implementation
JISF	Japan Iron and Steel Federation
OHF	Open Hearth Furnace
SEC	Specific Energy Consumption
SR	Smelting Reduction
ULCOS	Ultra Low CO_2 Steel Making
WTO	World Trade Organization

1 The Iron and Steel Sector

The iron and steel sector has traditionally been considered an important industry for strategic reasons. In the past decades, increased international competition has led to more specialization whereby producers tend to focus specific markets and customers. The European steel industry has gone from being an actor supplying the manufacturing industry with raw materials to being an integrated part of product manufacturing. The focus on high-quality and innovative products has granted the European iron and steel sector a prominent position on the global market for iron and steel products. However, with increasing iron and steel production in China and other countries, European industries are facing new challenges. This is exemplified by the fact that, although the European demand for steel is increasing, the domestic production is not. The increased demand is instead met through imports (ECORYS SCS Group, 2008).

The iron and steel sector is the second largest industrial consumer of energy in the world, only after the chemical and petrochemical industry. Steel production has increased continuously in the last two decades. Crude steel production has doubled, with major increases being observed in Asia, particularly in China. In 2010, 1.4 billion tonnes of crude steel were produced globally of which 15 % was produced in Europe. In 2007, the iron and steel sector consumed 26 EJ for the production of 961 million tonnes of pig iron and 1 351 million tonnes of crude steel, among other commodities (International Energy Agency, 2010; World Steel Association, 2010).

The energy intensity of processes used for European steel production is close to the thermodynamic minimum for the processes required for steel refinement and at an overall level comparable with the most energy efficient steel producing regions in the world. Due to this fact, current research on improving steel production processes is focused on reducing greenhouse gas (GHG) emissions rather than energy intensity (Birat et al., 2008). However, there is still potential for reducing energy intensity of the whole value chain of steel production, for example by reusing excess heat from steel production in other sectors.

New low-carbon technologies for iron reduction and steel production are currently being developed. These technologies are thought to be able to reduce the CO_2 emissions from steel production by 50 %. These new technologies are still at a development stage and implementation is foreseen in roughly 20 years' time (Birat, 2009). The implementation will require large commitments from the industry, not only in terms of investments but also through the interruptions in production that the introduction of new processes may require.

Competing with increased production capacities in China is a difficult task for European industries. Stringent climate change mitigation policies combined with increased competition from overseas production is indeed a major challenge for European steel producers striving to simultaneously reduce emissions and remain competitive. To reach high targets on energy efficiency improvements and emission reductions, actions are required in a coordinated fashion from all actors connected to the value chain of steel products.

In this report, an overview of the iron and steel sector is given at a global level, highlighting the energy requirements for production in selected regions. The major challenges being faced by European industries are discussed, as well as the actions needed for reaching a greener iron and steel production while also remaining competitive in the global market. The need to define new system boundaries for dealing with the impacts of the iron and steel industry are particularly highlighted in line with the contributions that ESA^2 can bring in this context.

1.1 Objective of the report

In this report, ESA^2 aims to identify action areas for ensuring the competitiveness of European iron and steel producers in a context of stringent climate change mitigation requirements and increased global market competition. The focus is on issues that are specific to the iron and steel industry, and which require particular attention of government and industries.

Clearly, defining policies, allocating resources and deciding on strategic investments of the size implied require a good knowledge base. The knowledge needed goes beyond the specific sector in focus as new goals will have to be defined at the strategic level, requiring a broader system approach and involvement of multiple stakeholders. Thus stakeholders, i.e. iron and steel producers, other companies connected to the value chain of steel production, government institutions and the European Commission need comprehensive assessments and in-depth analysis that provide support for decision making so that new goals and priorities can be jointly defined for the industry.

This report provides the broad contextualized background of the challenges being faced by the iron and steel industries in Europe, serving as a first step in this direction. Assessments tailored for specific stakeholder groups can be further developed by ESA^2.

1.2 Methodology

A statistical analysis has been performed to highlight the energy use patterns of key regions in the iron and steel sector. The statistics have been provided by United Nations Statistics Division (2011) for data on energy use and World Steel Association (2010) for data on production of commodities in the iron and steel sector, unless otherwise specified. The primary energy mix for electricity used in the iron and steel sector is assumed to be the regional electricity mix provided by the International Energy Agency (2011b). Conversion factors for energy data are estimated based on data from Eurostat (2004).

The energy use statistics refer to the iron and steel sector as reported in the ISIC Rev.4[1] standard, section D241 (manufacturing of basic iron and steel) and D2431 (casting of iron and steel). This system boundary means that neither the energy use related to the mining activity of iron ore and coal nor the energy used for refining coal into coke is included in the statistics.

The statistical analysis provides the basis for identifying global trends in production and energy use in the sector. Besides the absolute quantities on energy use and production, an energy intensity indicator has been calculated. Indicators on the energy intensity of production are commonly used to facilitate the discussion on energy use in manufacturing industries. For the iron and steel sector, the Specific Energy Consumption (SEC) is often

[1] The International Standard Industrial Classification (ISIC) of All Economic Activities, Revision 4 (United Nations Statistics Division, 2012).

used. Throughout this report, the SEC has been used as an indicator for discussing energy efficiency development in key regions.

$$SEC = \frac{Sectoral\ energy\ use}{Crude\ steel\ production}\ \text{in}\ \left[\frac{GJ}{tonne}\right]$$

However, the SEC is not totally accurate as a measure of the energy intensity in iron and steel production. Since the SEC uses a homogenous product as denominator, that is the crude steel, information on the quality of the product is lost. Furthermore, this calculation method assumes that all energy using activities within the sector are towards producing crude steel, which is not the case since the sector produces and sells other commodities, such as pig iron (Worrell et al., 1997; Schenk & Moll, 2007; Energimyndigheten, 2011a). Thus the SEC should only be considered as indicative of the energy efficiency levels in the iron and steel sector. Due to the lack of a better indicator, we chose to use the SEC as a starting point, despite the on-going discourse on its robustness.

1.3 The iron and steel production processes

The iron and steel production processes extend over a dozen process steps that vary largely among different regions worldwide, resulting in different patterns of energy demand as well as GHG emissions. To simplify, the iron and steel industry is commonly seen to have two major production routes for producing crude steel, which then can be further refined and used in the manufacturing sector. The primary route represents crude steel produced from iron ore and the secondary route represents crude steel produced from scrap. These routes differ in terms of steel characteristics, energy demand and resource requirements. The primary route includes several interchangeable process steps, as shown in Figure 1 (World Steel Association, 2008; International Energy Agency, 2007).

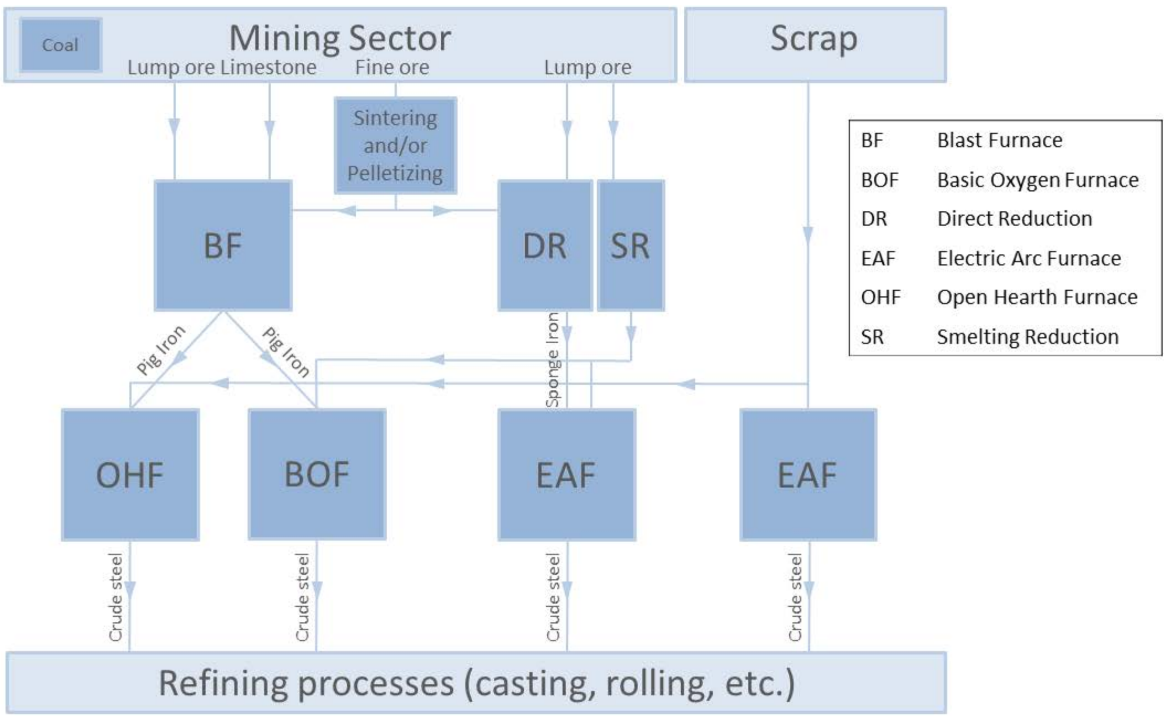

Figure 1: Steel production - process routes and material flows

In the primary route, iron ore is reduced into iron and then refined into crude steel. The iron reduction process can be done using several process alternatives. The most common is the blast furnace (BF), which produces an intermediary product called pig iron. Pig iron is then refined into crude steel in a basic oxygen furnace (BOF) or an open hearth furnace (OHF). An alternative process to the BF is the process of direct reduction (DR) of iron ore. DR is less widespread than BF and is suitable in regions where iron ore with high iron content is available, together with abundant natural gas and coal resources. The sponge iron, as the iron produced in DR is called, is used as feedstock for the electric arc furnace (EAF). In the secondary production route, steel is produced from scrap (ferrous metal wastes) using the EAF process. It should, however, be noted that some steel products require virgin materials which means that the primary and secondary routes are not completely interchangeable, even in a context of unlimited supply of scrap (Gojić & Kožuh, 2006; International Energy Agency, 2007; U.S. Environmental Protection Agency, 2007).

Energy demand and production

The two process routes, and the process steps they include, have different characteristics from an energy demand and GHG emissions point of view. The energy demand per ton of crude steel produced can vary with a factor four depending on the choice of processes. Table 1 shows the energy intensity in the different routes based on estimations by World Steel Association (2008), and the GHG emissions per ton of crude steel as estimated by International Energy Agency (2007).

Processes	Energy demand [GJ/t]	CO_2 emissions [tCO_2/t]
Primary route – BF/BOF	19.8 – 31.2	
- **Advanced BF**		1.3 – 1.6
- **Present average BF**		1.5 – 1.8
Primary route – BF/OHF	26.4 – 41.6	
Primary route – DR/EAF	28.3 – 30.9	
- **Coal-based**		2.3 – 3.0
- **Natural gas-based**		0.7 – 1.2
Secondary route – Scarp/EAF	9.1 – 12.5	0.3 – 0.5

Table 1: Energy and emission intensities of steel production processes

Globally, about 75 % of the crude steel is produced through the primary route and 25 % through the secondary route. It is also worth noting that the EAF is powered by electricity in contrast with the BF and the BOF/OHF. This means that shifting towards the EAF process would enable fuel switching towards renewables or other low carbon electricity production, implying lower GHG emissions. The secondary route, using EAF with scrap as feedstock, is the most favourable. However, as previously mentioned, it cannot completely replace the primary route due to the requirement of virgin materials for certain products and due to the limited availability of scrap. The low use of scrap in several countries does indicate a potential for increasing production using scrap as feedstock (Bureau of International Recycling, 2011; World Steel Association, 2008).

The classical BF is dependent on coke for the reduction of iron ore and, hence, requires coal to be refined into coke before use in the BF. Figure 2 shows the main energy demand patterns for the major processes. Coke-making is performed in a coke oven, which is often integrated with the BF in an integrated steel mill together with the BOF or OHF and refining processes. Both the coke oven and the BF produce exhaust gases which can be used in the process or for electricity generation. Currently, the use of biomass in iron production is concentrated to independent small-scale production plants in Brazil, but research on using biomass in iron production is currently being performed in several other regions. The type of biomass seen as most interesting for the iron and steel sector is biochar. Biochar has similar characteristics to coal or coke and is produced through pyrolysis. Z. W. Hu et al. (2011) see major potential for using bioenergy in iron production and conclude that the use would not only reduce CO_2 emissions, but also SO_2 and NO_x emissions. Because of its high energy demand, the BF process is seen as the most important for energy efficiency improvements and GHG emissions reductions (Z. W. Hu et al., 2011; International Energy Agency, 2007; van Wortswinkel & Nijs, 2010).

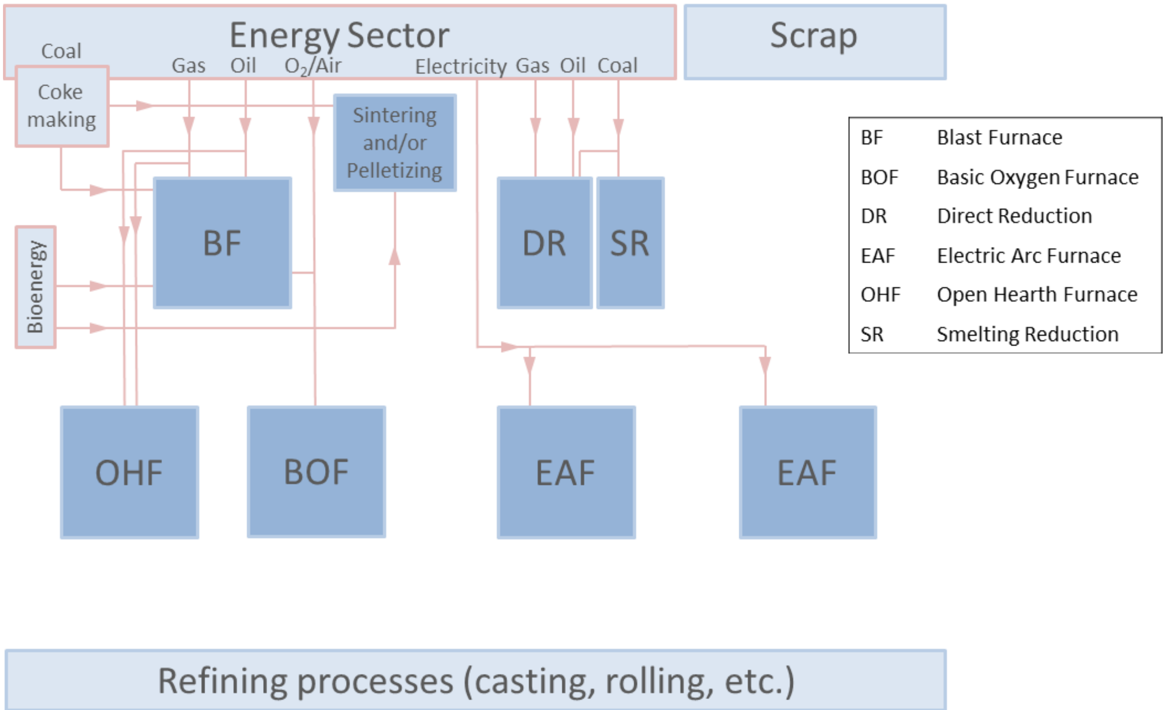

Figure 2: Energy input flows to steel production processes

When it comes to the refining processes from iron to steel, the BOF only requires very small amounts of additional energy. Also, the BOF produces exhaust gases which can be used in the iron production process in an integrated steel mill or for electricity generation. The OHF is energy intensive and seen as obsolete. Replacing OHFs with BOFs is seen as a means for reducing the energy demand for steel production and this has already been done in many parts of the world. OHF is, however, still used in several CIS countries, such as Ukraine and Russia. The EAF process is powered by electricity and, therefore, the GHG emissions from this process depends on the specific electricity mix of the country in question (International Energy Agency, 2007).

The DR process uses coal or natural gas for the reduction of iron ore. The natural gas DR is dominant (in 2000, over 90 % of all sponge iron was produced using natural gas). The GHG emissions are more than doubled if coal is used in its direct form in the DR process instead of natural gas. Besides DR, another process alternative is Smelting Reduction (SR) in which, comparable with DR, no coking is needed. SR produces hot metal from ore in two steps: a first step accomplishes a partial reduction, followed by a second step when complete reduction and melting of the metal is achieved. An advantage of the SR process is that investment costs are far lower if compared to the BF route. Besides the investment costs, the coal used can be of lower quality, thus also avoiding coking and related emissions of air pollutants (PM, SO_2, NO_x). Energy consumption is nominally higher in the SR than in the BF route, but for a correct comparison, one has to take into account the large amount of gas generated that can be used for electricity production or, when treated, for reuse as a reducing gas in the blast furnace (International Energy Agency, 2007; van Wortswinkel & Nijs, 2010). Furthermore, it is technically possible to replace large amounts of the coal used in SR with charcoal (Birat et al., 2008).

There are different smelting reduction processes which started appearing from 1980, some of which continue being developed. All have specific injection methods for coal, coal consumption rates, process efficiency, etc. (Steel Authority of India Limited, 2012; Luiten, 2001):

- COREX: coal reduction process, developed by Voest-Alpine industries and DVAI
- DIOS: Direct Iron Smelting Reduction, developed by Japan Iron and Steel Federation
- AUSMELT: developed by Ausmelt Ltd. Australia
- HISMELT: developed by CRA ltd., Australia and Midrex Corporation , United States
- ROMELT: developed by Moscow institute of steel and alloys in Russia
- Plasmasmelt: developed by SKF in Sweden

The COREX technology is the only process that has achieved commercial application today. A HIsmelt process on a commercial scale will be integrated in an existing steel plant in India by 2014 (Australian Mining, 2012). However, the future of smelting reduction technology is still somewhat open.

Since most processes in iron and steel production are heat intensive, there is large potential for using the excess heat created. Excess heat can be extracted in many ways, for example as steam (which is often used inside the mills) or as radiant heat which can be extracted using heat exchangers. Furthermore, the coke-making process produce coke breeze which is the small-sized coke not suitable for the BF. The coke breeze can instead be used as fuel input in the sintering process. There are also studies showing potential for using biomass in the sintering process instead of coke breeze (Ooi et al., 2011; International Energy Agency, 2007; V. Martin & Setterwall, 2008; Johansson & Söderström, 2011).

Furthermore, there are other by-products from steel production that can be used in the production of cement. These by-products are foundry sand, mill scale and slag. In the casting of iron, steel and other metals, foundry sand is used in the mould in which the metal is casted. When the sand has lost its quality for casting it has to be discarded and can then be used in cement production. Mill scale can be found on the surface of the steel during different stages of the refining processes. Mill scale can be recycled within the steel mill, but can also be used for cement production. Finally, slag can be found as a by-product in iron and steel production processes, from the BF (blast furnace slag) as well as from the BOF and EAF (steel slag) (Portland Cement Association, 2005).

Steel recycling

As mentioned above, the secondary route is completely dependent on ferrous scrap for steel production. The recycling of steel is particularly important since the used steel is already refined and, therefore, requires much less energy when being reprocessed into crude steel. The global scrap use for steelmaking was 530 million tonnes in 2008, reported by Bureau of International Recycling (2011), and steel scrap is seen as one of the most important raw materials in the sector. The World Steel Association (2010) estimate the crude steel production to 1 327 million tonnes in 2008. Together these numbers indicate a 40 % scrap use for crude steel production in 2008.

Scrap can be divided into three subcategories: home scrap, new scrap and old scrap. The home scrap has its origin in the production process of steel and is therefore high in quality, and located within the factory gates. It amounts to about 20-30 % of the accumulated scrap. The new scrap originates from the production of steel products. The new scrap amounts to about 15-25 % of the accumulated scrap. The old scrap is the largest source of metal scrap available, 40-55 % of the accumulated scrap. The old scrap originates from products which have reached their end-of-life and may contain large amounts of residual elements. The chemical and physical properties of the new scrap and home scrap are well known, which facilitates the recycling process in contrast with the situation when using old scrap (Yellishetty et al., 2011).

Energy efficiency benefits and GHG emissions reductions are interlinked with the use of scrap in steel production, as shown in Table 1. Increasing the amount of scrap available could help reducing the energy demand and emissions of the sector. A Swedish initiative, *Stålkretsloppet,* aims to enable knowledge transfer in a multidisciplinary manner between research and industry in different sectors of the economy to increase the recyclability of the scrap potential. The companies include steel producers, the recycling industry as well as several manufacturing industries, in segments such as car production, home appliance production, etc. Transferring best-practice in recycling between countries could increase the available amount of scrap in Europe (Stålkretsloppet, 2012).

2 Production on a global market

The global crude steel production has been continuously increasing during the last two decades, as depicted in Figure 3.The global production has almost doubled over the time-period mainly due to the Asian development, where China is the major contributor. In 2010, China was responsible for 44 % of the total global crude steel production. Other regions suffered from production decreases during 2008-2009, which may have been due to the global recession during those years. However, the crude steel production in Asia only slowed down slightly during 2008-2009 and not at all in China.

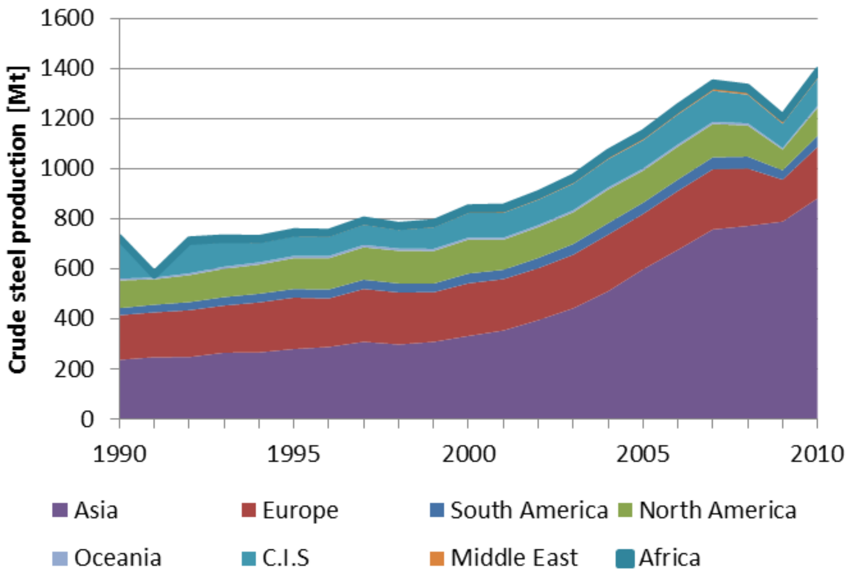

Figure 3: World crude steel production, 1990-2010

Source: World Steel Association (2010).

Lin et al. (2011) investigate the inter-linkage between steel demand and development. According to the experience of developed countries, the iron and steel sector is one of the sectors which grows most rapidly during industrialization and act as a catalyst to economic growth. Hence, an important indicator for the iron and steel sector development is the per capita use of steel. Logically, the demand for energy for steel production will follow a similar pattern unless major process changes occur. However, when the market for steel products is saturated, the demand tends to stabilize. Historically, this has happened at a consumption level of 650 kg / capita in Japan, 600 kg / capita in the U.S. and 500 kg / capita in the U.K. In 2010, the steel use was 445 kg / capita in China, indicating that China is reaching usage levels comparable with developed countries. Steel use in India, South Africa and Brazil are still much lower. In 2010, the steel use in these countries was 56 kg / capita, 97 kg / capita and 147 kg / capita, respectively. If the reasoning of Lin et al. (2011) is applied, significant growth in iron and steel demand can be expected in emerging economies. The development of steel use per capita is shown in Figure 4 for the largest consumers, and for the EU and the world. While China as well as the world as a whole is gradually increasing the use of steel, a decreasing trend is observed in developed countries, especially during the 2008-2009 recession.

Holloway et al. (2010) compare the steel production per unit of GDP with the GDP per capita for two developed economies, United States and Japan, and for two emerging economies, China and India. The trend shown for the developed economies is that steel production per GDP increases drastically when GDP per capita starts to increase, but as the GDP per capita grows the steel production per capita reaches a peak and then slowly decreases. In 2009, it can be seen that China is climbing towards the peak, while India is still in the very start. The authors argue that provided that China follows the pattern of the developed economies, a decrease in steel demand should be expected in a few decades connected to the expansion of the service sector.

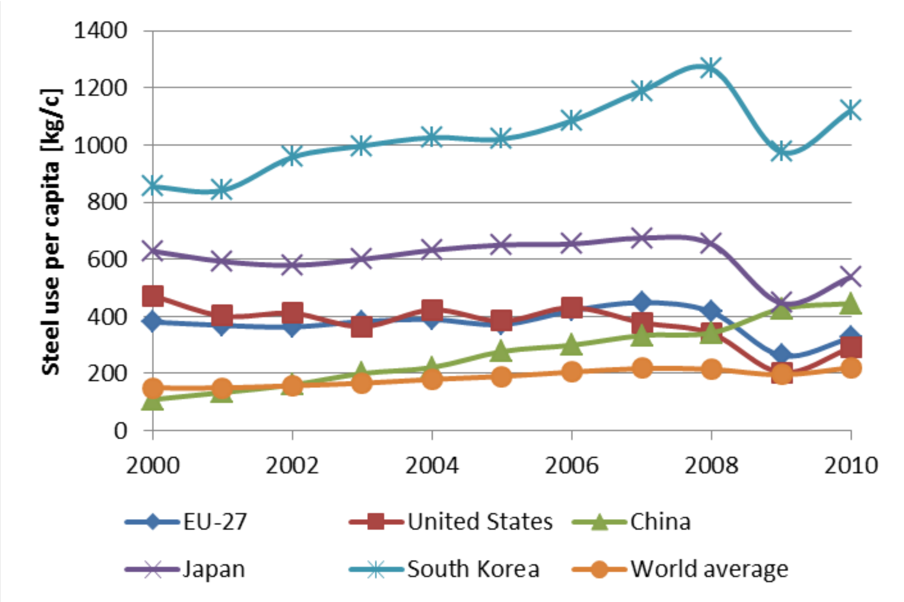

Figure 4: Steel use per capita, selected countries and regions

Source: World Steel Association (2010).

Hu et al. (2010) investigate Chinese steel demand patterns in the residential sector, which is responsible for approx. 20 % of the steel demand in China. The results of the study show a decrease in steel demand over the coming 20 years largely due to the increased life-time of buildings in China. This indicates potential environmental benefits if construction decreases. However, as the steel demand oscillates and also gradually decreases this could lead to overcapacity and uncertainties for the iron and steel producing companies in the country.

A study developed for Competition Commission of India suggests that steel consumption in India is an indicator of development. Steel use per capita in India, 48 kg/capita for 2008, is well below the world average of 214 kg/capita in the same year. The iron and steel sector is today highly prioritised in Indian policies. The National Steel policy, which was introduced in 2005, sets a target of reaching domestic production levels of 110 Mt of crude steel by 2020 compared to 67 Mt in 2010 (Indicus Analytics, 2008; World Steel Association, 2010).

Vertical integration and trade of intermediary commodities

So far, only the crude steel production has been discussed. There are several commodities needed in the supply chain of steel production and these commodities are traded in a global market. The production of iron ore, pig iron, sponge iron and crude steel are distributed unevenly among different parts of the world. The distributions show that a few key regions are vital in the operation of these supply chains. In Table 2, the top five producers of iron ore, pig iron, sponge iron, crude steel as well as the top five steel using regions are shown. China is the most important region for the iron and steel sector, being the top producer of iron ore and pig iron as well as the top producer and user of crude steel. Other important regions are the European Union (EU-27), Japan, India, Russia, the United States and Brazil through their different roles along the chain.

	Iron ore		Pig iron		Sponge iron		Crude steel		Steel use	
	China	21%	China	50%	India	31%	China	38%	China	35%
	Australia	20%	EU-27	12%	Iran	11%	EU-27	15%	EU-27	13%
	Brazil	20%	Japan	9%	Venezuela	10%	Japan	9%	United	8%
	India	12%	Russia	5%	Mexico	9%	United	7%	Japan	6%
	Russia	6%	India	4%	Russia	7%	Russia	5%	South Korea	5%
World (Mt)		1 723		935		67		1 329		1 299

Table 2: Top five countries in production of iron ore, pig iron and crude steel, and top users of steel, 2008.

Source: World Steel Association (2010).

The year 2008 is chosen since data is incomplete for 2010. Using data from 2009 might overestimate the production and use in China since the Chinese iron and steel sector was much less affected by the global recession than other parts of the world, see Figure 3.

As indicated in Table 2, the iron and steel sector competes in a global market and activities are often concentrated in major companies or networks of companies. It is also common with vertically integrated facilities, where the chain from iron production to casting and rolling of the finished steel is done in the same facility. Coke ovens are often integrated in these types of facilities, which is important to note when discussing energy use statistics since the coke oven will not be included in the section for iron and steel production.

The vertical integration and co-location is particularly attractive due to the weight of the commodities in the iron and steel sector. However, the sector still has major needs for transportation and hence also for energy associated with the transportation. Yellishetty et al. (2010) assess the mass flows in the iron and steel sector between major regions globally. Their study shows, in accordance with the statistics shown in Table 2, that the iron and steel sector is largely dependent on international trade of commodities and, hence, also on transportation of these commodities. Sea borne transportation is the preferred mode of transportation in the sector. A first estimation of the emissions linked to transportation in the iron and steel sector indicates that the CO_2 emissions from crude steel production would increase by 10-15 % if the energy used in the sea borne transportation of the intermediary products were to be included.

Crompton & Lesourd (2008) suggest that competitiveness in iron making primarily depends on two phenomena: the price of iron ore and economies of scale. The high fixed costs in the industry have encouraged merges and takeovers. Furthermore, the authors argue that labour and capital costs have a low influence on competitiveness, and thus countries with low labour costs are not necessarily more competitive. Competitiveness is also influenced by energy prices, but to a lesser extent according to the study.

3 Energy intensities of some key regions

A major challenge for the iron and steel sector is to reduce its environmental impact, particularly GHG emissions. The major GHG emissions from the steel production of today is related to direct and in-direct energy use. When discussing energy use and GHG emissions of steel production, a systems approach is necessary.

At national level, the GHG emissions and energy use induced by imports are often omitted. Embedded energy and GHG emissions may be hidden in trade, and can have large consequences for the sector if considered in the formulation of energy and climate policy. Wagner (2010) confirms that the emissions and energy hidden in trade is an area of research that may become crucial for policy design as a way to increase competitiveness. To reduce the overall environmental impacts of manufacturing and use of products, the decoupling of energy and greenhouse gas emissions is especially important. As a result, for some products, the energy content might be allowed to increase as long as the overall accumulated CO_2 emissions decrease. Tanaka (2008) exemplifies that the use of lightweight steel in passenger cars leads to a decrease in steel demand for the car production, and fuel demand during the lifetime of the car. These environmental benefits would not be visible if the analysis were limited to a narrow system boundary, for example focusing only on the production of the lightweight steel, which is more energy-intensive than the production of regular steel. Hence, from a sustainability point of view, a broader systems approach is favourable since the system wide greenhouse gas emissions reductions are what motivate the energy efficiency improvements.

However, indicators using a systems oriented approach and describing the energy intensity of the whole value chain are not readily available. In this report, a commonly used indicator of energy intensity is thus presented as a starting point for discussions. This indicator, the Specific Energy Consumption (SEC), gives a crude indication of the energy use for steel production in a few selected regions. The situation in each country is discussed in more detail, focusing on the regional production and energy use as well as the trends of the sector and the potential for energy efficiency improvements and GHG reductions.

Global trends in energy intensity

The regional differences in energy demand of iron and steel production are large, as indicated by the energy intensities shown in Figure 5. The sector is highly dependent on fossil energy sources for the iron reduction part of the process. The only region with direct renewable energy sources in the production is Brazil, where charcoal is largely used. Some other regions also use renewables in-directly, that is depending on the renewable share in the national electricity mix.

Regions of special importance for the iron and steel sector are shown in Table 2 and nine of these have been selected for a deeper discussion. The selected regions are four emerging economies (Brazil, Russia, India and China) and five regions with traditional stake in the global iron and steel production (EU-27, Sweden, Belgium, Japan and the United States).

The global average energy intensity of steel production has been steadily decreasing since the 1950's. Yellishetty et al. (2010) show an exponential decrease and identify two major shifts influencing this trend. The first is the shift towards more efficient steel production processes within the primary production route, primarily shifting from OHFs to BOFs in the refining of iron to steel. The second is a shift towards the secondary production route, increasing the use of scrap and also the use of direct reduced iron for steel production, both of which requiring less energy in the production process. The authors predict future global average energy intensities of 14.5 and 12 GJ per tonne of crude steel produced in 2020 and 2030 respectively. The analysis is based on statistics from seven countries and limited time series only. More in-depth understanding and conclusions on these trends would require a deeper investigation of the energy intensity within the various segments of the sector as well as deeper exploration of the structural differences between different regions. The picture is, in fact, very complex because energy demand is not only affected by differences in the production methods but also varying institutional and structural settings.

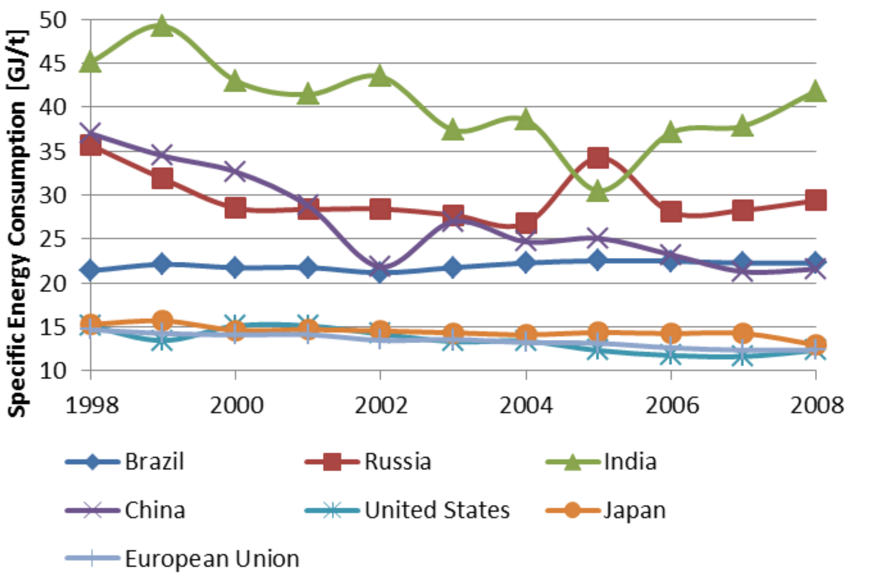

Figure 5: Energy intensity of crude steel production in selected regions (GJ/t crude steel)

Source: World Steel Association (2010) and United Nations Statistics Division (2011).

The SEC is very dependent on the processes used. Previously, the EAF process has been described as much less energy intensive than BOF or OHF, especially when using scrap as feedstock. To provide a deeper analysis of the energy intensity in steel production in the selected regions, a graph is provided where the SEC is shown as a function of the share of EAF use in the same region for the year 2008, see Figure 6.

When comparing SEC of different countries and regions, the World Energy Council (2008) suggests that only SEC in regions with similar process structures should be compared. In Figure 6, the group of developed countries stand out as being more similar and the emerging economies as being more diverse. India is especially different both in terms of SEC and share of EAF for steel production compared to the other countries. The SEC reported for India for 2005 is only roughly half of that reported for India in 2008 (World Energy Council, 2008). This is intriguing but a deeper analysis of the data is required if any conclusions are to be drawn. The instability of the SEC for India, clearly shown in Figure 5, could denote data problems but, in any case, these large variations in the SEC illustrate the indicative nature of the SEC for estimating the energy efficiency in the whole sector as already pointed out in the methodology section above.

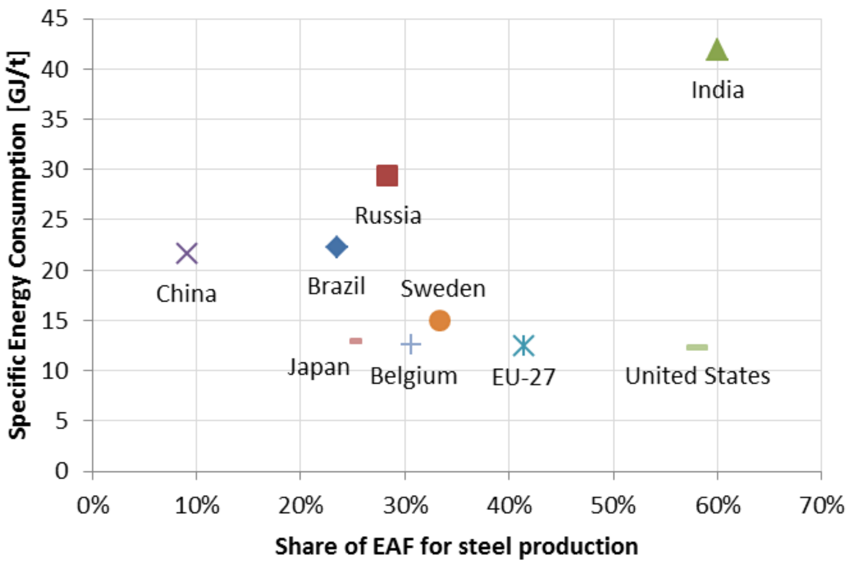

Figure 6: SEC as a function of the share of EAF production in 2008

Source: World Steel Association (2010) and United Nations Statistics Division (2011).

Primary energy use

The primary energy use depends on the technology choices in the iron and steel sector as well as the electricity sector composition in the region where production takes place. The final energy use data from United Nations Statistics Division (2011) were converted to primary energy assuming that the regional electricity mix provided by the International Energy Agency (2011b) is representative for the electricity consumed to produce steel. The conversion factor for region specific electricity production from primary energy sources were taken from International Energy Agency (2008).

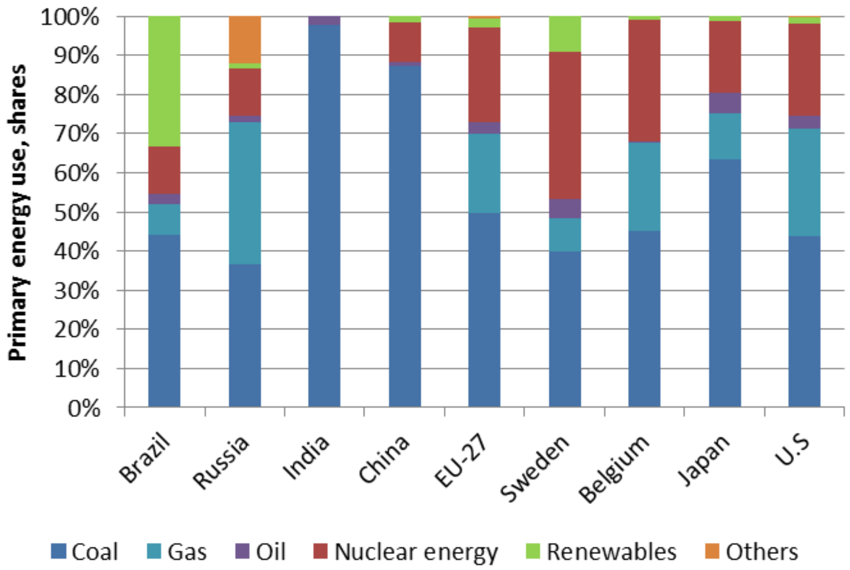

Figure 7: Shares of primary energy use in the iron and steel sector in 2008

Source: World Steel Association (2010), United Nations Statistics Division (2011) and International Energy Agency (2011b).

Figure 7 shows the relative shares of the different primary energy uses in the iron and steel sector of selected countries. The primary use of coal ranges from 36% in Russia to 98% in India. Natural gas is the second largest fossil energy although some regions do not use any natural gas. Russia has the highest share of natural gas, with 36% in the energy mix of the sector. When a higher share of EAF is used and when nuclear is part of the electricity mix of a region, the importance of nuclear energy quickly grows as a source of primary energy to produce steel. Nuclear power plants are limited to convert only about one third of the primary energy, showing a higher share for nuclear of 20% or more in EU-27, Sweden, Belgium and the United States. Renewable energy is significant in Brazil and Sweden only.

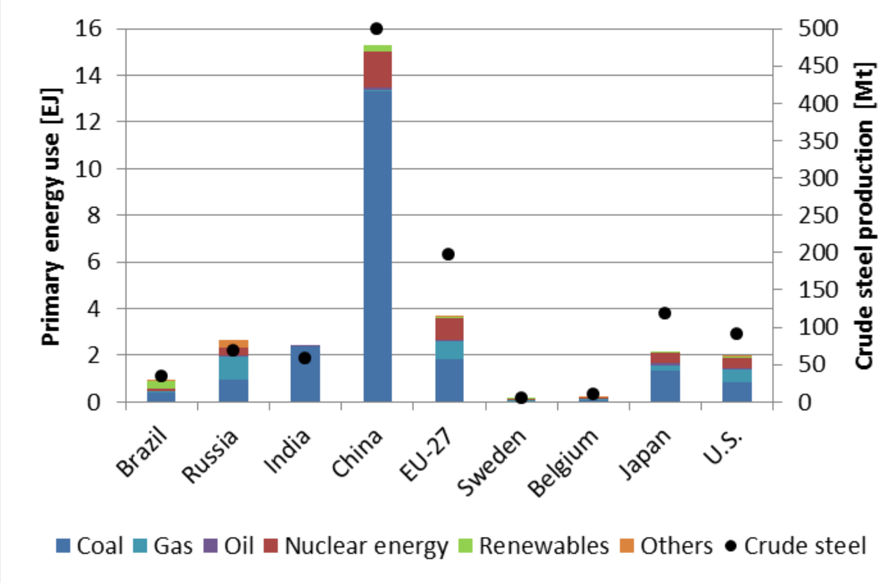

Figure 8: Primary energy use, in EJ, and crude steel production, in million tonnes, in the iron and steel sector 2008

Source: World Steel Association (2010), United Nations Statistics Division (2011) and International Energy Agency (2011a).

The absolute primary energy use is shown in Figure 8 for the selected countries. Smaller countries disappear in the overall picture and it is clear that the role of China is crucial. China has a primary energy use for the production of steel that is larger than the sum of the eight other regions. The top three of the primary energy sources used in the regions covered are coal (72%), nuclear energy (13%) and natural gas (9%), explaining 94% of the total primary energy use. Renewable energy accounts for 2.5% of the total primary energy envisaged.

	Brazil	Russia	India	China	EU-27	Sweden	Belgium	Japan	U.S.
Crude steel production	33.7 Mt	68.5 Mt	57.8 Mt	500 Mt	198 Mt	5.20 Mt	10.7 Mt	119 Mt	91.4 Mt
Pig iron production	34.9 Mt	48.3 Mt	37.3 Mt	469 Mt	108 Mt	3.58 Mt	6.98 Mt	86.2 Mt	33.7 Mt
Sponge iron production	0.302 Mt	4.56 Mt	20.9 Mt	0.600 Mt	0.645 Mt	0.125 Mt	-	-	0.260 Mt
Iron ore production	346 Mt	99.3 Mt	214 Mt	366 Mt[2]	26.5 Mt	23.8 Mt	-	-	53.0 Mt
Scarp use	N/A	20.1 Mt	N/A	72.0 Mt	111 Mt	N/A	N/A	44.8 Mt	66.0 Mt
Steel use per capita	138 kg/c	289 kg/c	48 kg/c	343 kg/c	416 kg/c	559 kg/c	506 kg/c	653 kg/c	340 kg/c
Energy use	751 PJ	2 010 PJ	2 420 PJ	10 800 PJ	2 450 PJ	77.6 PJ	134 PJ	1 540 PJ	1 130 PJ
SEC	22.3 GJ/t	29.4 GJ/t	41.8 GJ/t	21.6 GJ/t	12.4 GJ/t	14.9 GJ/t	12.6 GJ/t	13.0 GJ/t	12.3 GJ/t

Table 3: Production in Mt, energy use in PJ, and SEC in GJ/t, key regions 2008

Source: World Steel Association (2010), United Nations Statistics Division (2011) and Bureau of International Recycling (2011).

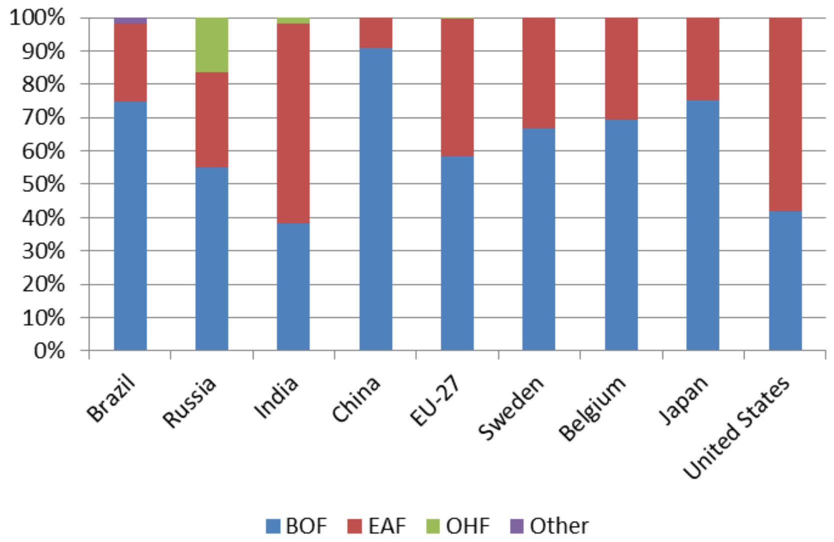

Figure 9: Processes for refining pig iron to crude steel, by country in 2008

Source: World Steel Association (2010).

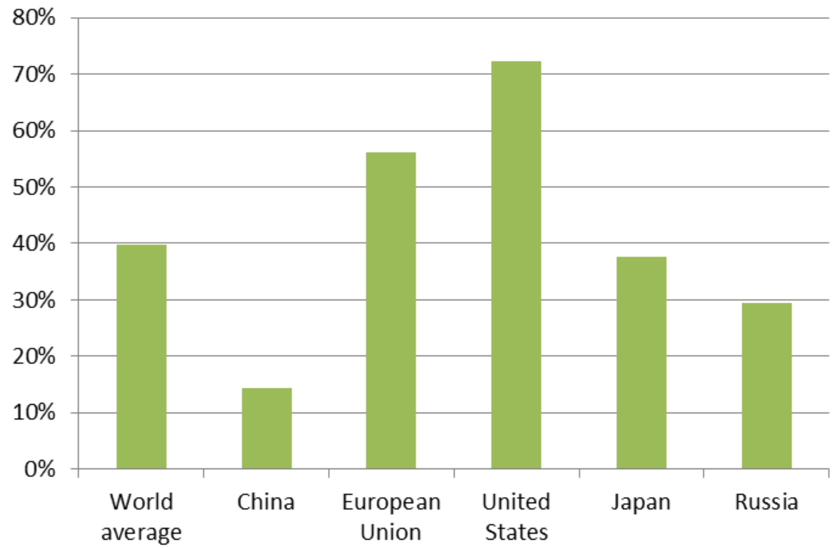

Figure 10: Ratio scrap use for steel production / crude steel, by country in 2008

Source: Bureau of International Recycling (2011).

[2] The Chinese iron ore is low in iron content. The reported quantity has been adjusted to resemble the world average iron content (World Steel Association, 2010).

3.1 Brazil

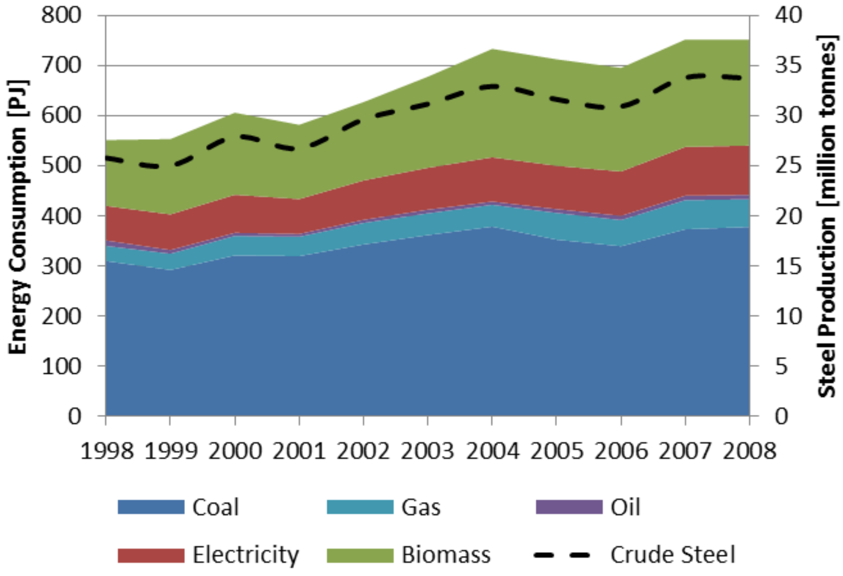

Figure 11: Energy use and steel production in the Brazilian iron and steel sector, 1998-2008

Source: World Steel Association (2010) and United Nations Statistics Division (2011).

Production and energy use

The Brazilian iron and steel industry can be divided into two groups of producers, large integrated producers and small independent pig iron producers. The group of large producers is characterized by multinational companies, such as ArcelorMittal and Companhia Siderurgia Nacional (CSN). The other group of producers is small independent pig iron producers. In 2008, the independent producers were responsible for roughly 24 % of the total pig iron production in Brazil. As previously mentioned, Brazil is one of the major iron ore producers in the world, which the company Vale is largely responsible for. The iron ore reserves in Carajás are especially interesting since they have a high iron content (66-67 %) compared to other reserves, for example the Australian (62-63 %) (Vital & Pinto, 2009; Thomas White International Ltd., 2010).

The Brazilian iron and steel industries are the only ones in the world using significant amounts of biomass as a direct energy source, amounting to 28 % of the final energy use in 2008 (see Figure 11). The biomass used in the sector was 97 % charcoal and 3 % vegetal wastes and fuelwood. The charcoal used is produced domestically and is used mainly in pig iron production by independent producers, but also in a few integrated steel plants. About 80 % of the electricity used in all Brazilian sectors was produced in hydro power plants in 2008. Another 4.4 % was produced from biomass and wind (International Energy Agency, 2011b; Ministério de Minas e Energia & Empresa de Pesquisa Energética, 2011). This means that the iron and steel sector in Brazil is powered by primary renewable energy sources at a rate of 33 % (see Figure 7), quite significant not least in comparison to other regions.

However, there is one downside to the use of charcoal. There is a clear link between the use of charcoal in iron production and deforestation. The use of biomass from native forest in Brazil was decreasing in the beginning of the 90’s, but only temporarily (Nogueira & Coelho, 2009). Even though the use of charcoal in iron production has environmental benefits compared to fossil coal, the origin of the charcoal has to be guaranteed to ensure sustainability and climate change mitigation. Using biomass derived as by-products in other production processes could alleviate the pressure that charcoal use puts on the forests and could also lead to benefits for stakeholders in other sectors.

Virtually all fossil metallurgical coal used in Brazil is imported. In 2008, Brazil imported 15 Mt of metallurgical coal and 0.26 Mt was produced domestically (Ministério de Minas e Energia & Empresa de Pesquisa Energética, 2011). This means that Brazilian iron and steel production largely depend on foreign coal supplies, which in turn makes research in lowering energy demand and switching to other energy sources even more important. The use of charcoal is a way of alleviating the dependence on imports, since the charcoal is produced domestically. Hence, increasing charcoal production under sustainable conditions is a current topic under research (Nogueira & Coelho, 2009; Vital & Pinto, 2009).

Regional trends and potential for improvements

During the last decade, the Brazilian production has been slightly increasing, but the SEC has remained stable (see Figure 5). The SEC is verified by comparing with another study done for the Brazilian Government. The SEC of Brazilian production was compared for 2002-2007 and the annual values lie within a margin of 5 %. The share of pig iron produced by independent producers has also remained stable, independent pig iron producers being responsible for roughly one fourth of the total pig iron production (Vital & Pinto, 2009; Ministério de Minas e Energia, 2009).

The Brazilian iron and steel production is expected to increase in line with large investments in infrastructure and increasing consumption of steel products. Also, the international demand for iron ore and steel is expected to increase in the future, providing large opportunities for the Brazilian metallurgical sector (Thomas White International Ltd., 2010).

A study prepared by the Brazilian Government confirms the expected expansion of Brazilian iron and steel production. The study indicates that the major expansions are expected to use the primary production route (steel production from iron ore), but with the possibility of using charcoal as reduction agent. It is estimated that 80 % of Brazilian crude steel will be produced using this route in 2020. Potential for improving energy efficiency in the primary production route is seen when comparing international best practice with the Brazilian SEC. The main improvement potentials reported are through plant integration with electricity co-generation and improving efficiency in coke ovens and steel refining processes (Ministério de Minas e Energia, 2009).

3.2 Russia

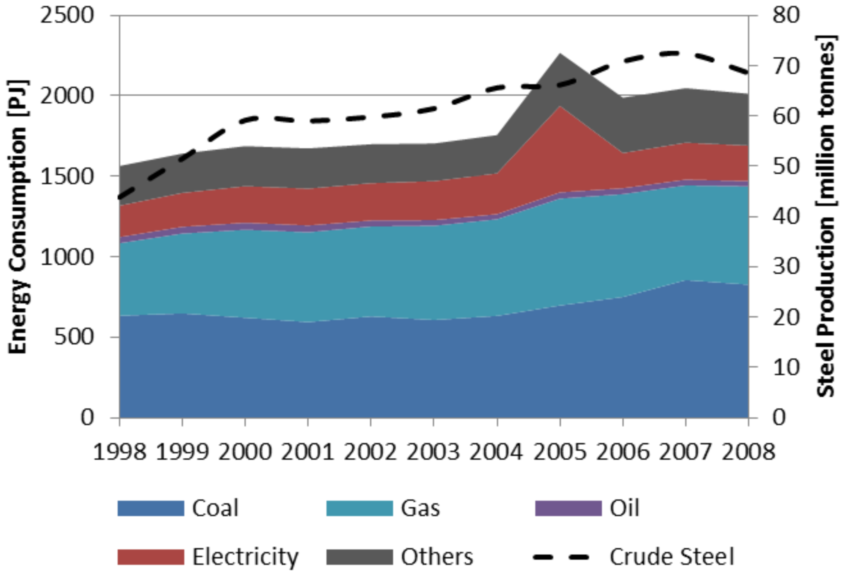

Figure 12: Energy use and steel production in the Russian iron and steel sector, 1998-2008

Source: World Steel Association (2010) and United Nations Statistics Division (2011).

Production and energy use

Energy supply in Russia is largely dependent on natural gas, which is seen also in the energy use of the iron and steel sector. A policy to reduce dependence on natural gas is in place and the use of coal is expected to increase to cover the gap. Notably, the Russian iron and steel sector was almost three times more energy intensive in 1995 than the U.S. iron and steel sector. Meanwhile, the slow energy efficiency development in the Russian industry in the 1990s was due to non-existing or weakly implemented energy efficiency policies. The traditional management of industries in a former Soviet state is also thought to be a reason for the low energy efficiency – the production lines were seldom closed even when demand decreased implying significant waste of energy (International Energy Agency, 2002).

Regional trends and potential for improvements

The SEC of Russian steel production is still high compared to other countries. However, the ratio between the Russian and the U.S. sector went down from 3 in 1995 to about 2 in 2008. 16 % of the Russian crude steel was produced using OHF in 2008 which can explain the high energy intensity (see Figure 5). The OHF process is significantly more energy intensive than both the EAF and the BOF. Investments in more efficient processes have been more frequent during the last years and the share of OHFs is expected to continue decreasing, reaching a level of 3-4 % in 2015 (Bazulev, 2009).

Russian production has a relatively low use of scrap compared to the developed countries and the world average, see Figure 10. Increasing the use of scrap and the EAF process could help reduce energy intensity of the overall production.

3.3 India

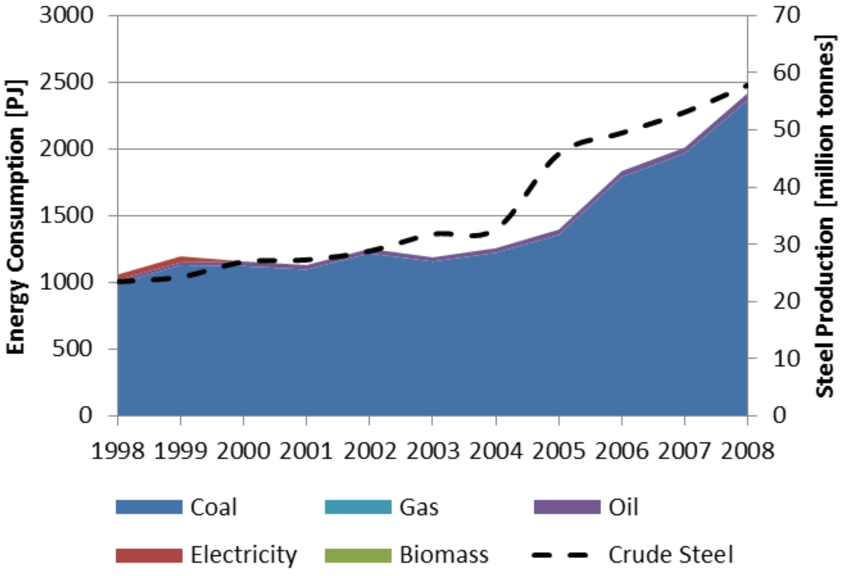

Figure 13: Energy use and steel production in the Indian iron and steel sector, 1998-2008

Source: World Steel Association (2010) and United Nations Statistics Division (2011).

Production and energy use

The Indian iron and steel sector can be split into two groups: major producers, which use integrated steel mills, and a diverse group of other producers, consisting of 120 sponge iron producers and approximately 650 mini plants (BFs, EAFs, and others). The latter are connected to 1200 companies who refine crude steel into semi-finished and finished steel products (Dutta & Mukherjee, 2010). Furthermore, India has significant iron ore reserves and is the fourth largest producer of iron ore globally, after Brazil, China and Australia (see Table 2).

The domestically produced coal in India is low in quality and not appropriate for coke-making. However, it is suitable for DR which is why DR has been favoured by the Indian industry. When using coal in DR, the route is more energy intensive and therefore contributes to the high overall energy intensity of the Indian sector. Furthermore, the Indian blast furnaces have relatively high average coke consumption (Gielen & Taylor, 2009).

The International Energy Agency (2011a) has identified lacks in energy data reported for India. Industrial electricity use is not reported in the different sub-sectors, but rather into a non-specific category, which may be the reason for the absence of electricity in data provided by United Nations Statistics Division (2011) as well. Furthermore, the system boundary used in data from India is different from the one specified by the International Energy Agency and used for data reporting by other countries. Hence, the data provided for India needs further verification.

Regional trends and potential for improvements

India is by far the most energy intensive region when it comes to steel production (see Figure 5). In 2005, average coke consumption in Indian blast furnaces was 30 % higher than the average in the EU-15 countries. This contributes to the high overall SEC reported for the Indian iron and steel sector together with the not fully exploited potential for waste heat recovery. Gielen & Taylor (2009) see potential for increasing the share of DR for iron ore reduction using coal. The authors indicate a projected SEC for the Indian steel production of 25 GJ/t in 2030. Even though that would indicate a significant decrease in SEC, it is still higher than the SEC observed in the developed countries today.

According to projections by Dutta & Mukherjee (2010) for 2031, the impact of expected improvements in India show a modest reduction of energy use, or only 8 % when comparing a business-as-usual scenario with an energy-efficiency scenario. This indicates that the Indian energy intensity of production will remain significantly higher compared to other regions. The authors describe the integrated producers in India as comparable with world standards, but with some potential for improvements which may be implemented without policy support. However, a large potential for improving energy efficiency is seen in the diverse group of non-integrated producers and the authors suggest that this group should be given policy attention to speed up the rate of efficiency improvements.

According to the projections developed by the International Energy Agency, 52 % of the reductions needed for reaching the target emissions in 2050 in India would have to come from emissions reductions in the iron and steel sector. These reductions are thought to be achieved by implementing best available technology, fuel switching from coal to gas in the direct reduction process (production of sponge iron), increasing recycling and carbon sequestration (International Energy Agency, 2011a).

3.4 China

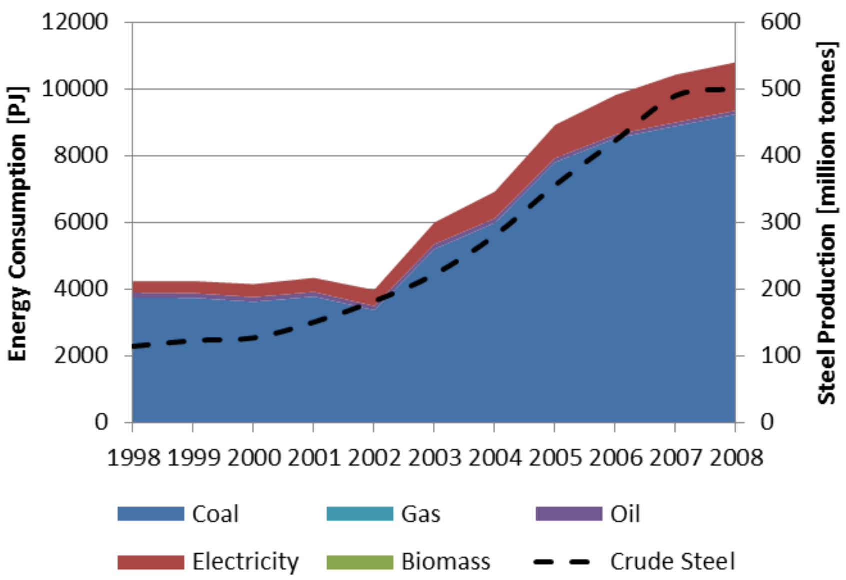

Figure 14: Energy use and steel production in the Chinese iron and steel sector, 1998-2008

Source: World Steel Association (2010) and United Nations Statistics Division (2011).

Production and energy use

China is in a period of accelerated industrialization and urbanisation. The demand for steel products has grown significantly during the last decade and is expected to continue increasing in the near future. The industries were given a higher degree of self-control in the 1980s and have, since then, improved facilities and increased capacity. The enhanced productivity of the Chinese iron and steel sector is thought to be linked to the opening up of the industries to international trade, which allowed transfer of more advanced technology into the country. Steel production in China is done through the primary route, using BF and BOF to 90 %. The focus on BOF rather than EAF can be traced to the uncertainties in electricity supply as well as the low availability of domestic scrap (Holloway et al., 2010; Lin et al., 2011).

China is one of the major iron ore producers globally, but the iron ore produced in China has significantly lower iron content than reserves in other parts of the world. The iron content of the Chinese reserves is only roughly 33 %, which is almost half of the content of reserves in Australia (62 %) and Brazil (65 %). The lower iron content means that the iron ore is more expensive to process. However, the avoided transport costs of alternative imported ore can compensate the more expensive domestic ore (Holloway et al., 2010).

The Chinese iron and steel production relies mostly on coal and electricity as energy sources, as seen in Figure 14. The Chinese electricity production is largely based on fossil sources, primarily coal, which accounts for approximately 81 % of the electricity in 2008. Other sources are renewables (17 %) and nuclear power (2 %) (International Energy Agency, 2011b). Since the Chinese iron and steel sector stands for the majority of iron ore, pig iron and steel produced globally, it is worrying to see that 97 % of the energy used in iron and steel production has a fossil origin. This is about 10.5 EJ, which is equivalent to about five times the total energy demand for the whole country of Sweden in 2010.

Regional trends and potential for improvements

The SEC in China has continuously decreased during the last decade (see Figure 5). According to estimations made by Lin et al. (2011), the SEC of Chinese iron and steel production will be as low as the Japanese (being one of the most energy efficient in steel production) between 2015 and 2020 depending on the rate of consolidation in the Chinese sector. The authors argue that, besides investments in energy conservation, R&D, and labour productivity improvements, the consolidation of companies in the Chinese iron and steel sector will help increase the total efficiency of the sector. Zeng et al. (2009) identify several barriers to reducing emissions in the sector, including the large number of small-size actors. Other barriers are the low use of waste heat and pressure, lack of financial support for small and medium size companies to invest in new and more efficient technology, lack of markets for electricity produced as by-product in the sector, and lack of energy management systems, especially for small and medium sized actors. The authors suggest implementation of policy mechanisms like clean development mechanism and voluntary carbon markets to increase the transfer of knowledge and capital into the Chinese industry. Furthermore, mandatory energy audits are thought to provide incentives for the industry to invest in more efficient technology, although better energy use statistics are required to provide benchmarking. Consolidation in the sector could eventually contribute to reducing environmental impact.

The use of scrap in steel production is relatively low in the Chinese crude steel production, see Figure 10. Increasing the scrap use could increase energy efficiency. However, Hu et al.

(2010) note that the longer lifespans of buildings in China may lead to less scrap being available as feedstock to steel production in the future.

3.5 European Union (EU-27)

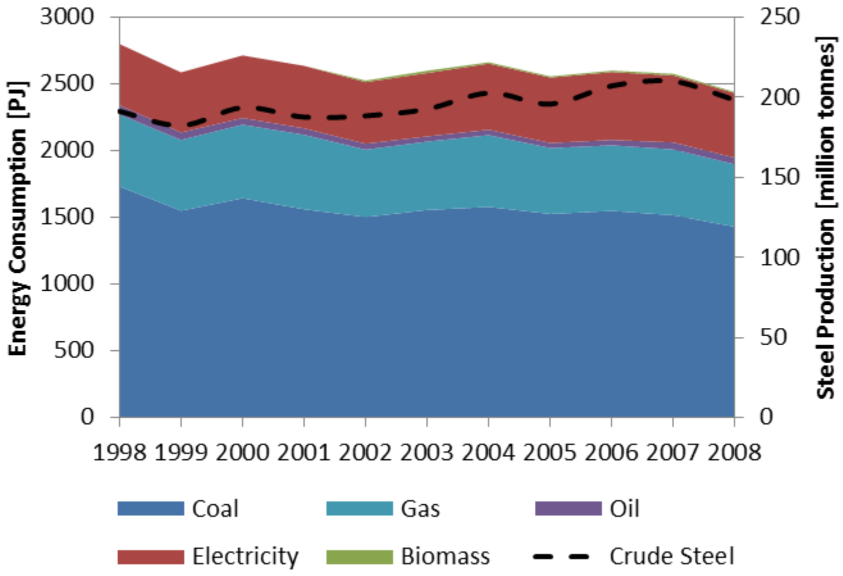

Figure 15: Energy use and steel production in the European iron and steel sector, 1998-2008

Source: World Steel Association (2010) and United Nations Statistics Division (2011).

Production and energy use

In 2008, the production of steel in the EU was 198 million tonnes, compared with Russia at 69 million tonnes and Japan, the US and China at 119, 91 and 500 million tonnes, respectively. The European iron and steel production is energy efficient compared to other key regions, having an average energy intensity comparable to both the United States and Japan. The low energy intensity of European production can be partly explained by the large use of scrap in steel production. In 2008, European companies used 111 Mt of scrap in their steel production, which is about 21 % of the worldwide scrap use (Bureau of International Recycling, 2011). During the last decade, the production levels have been stable in the EU and the energy consumption slightly decreasing.

Regional trends and potential for improvements

Electric arc furnace steel production has been gradually increasing in the EU. Nevertheless, according to the European IPPC Bureau (2010) the BF/BOF is expected to remain the dominant production route, at least in the medium term. To further reduce the environmental footprint of steel production, the European Commission supports a large research initiative called Ultra-Low CO_2 Steelmaking (ULCOS). The program aims to decrease CO_2 emissions by 50 % compared to today's best-practice and to deliver new process routes ready to be implemented within 15-20 years. It focuses on refining existing processes, developing completely new ones as well as promoting fuel switching towards renewable energy sources (e.g. biomass) (Birat et al., 2008).

Sweden

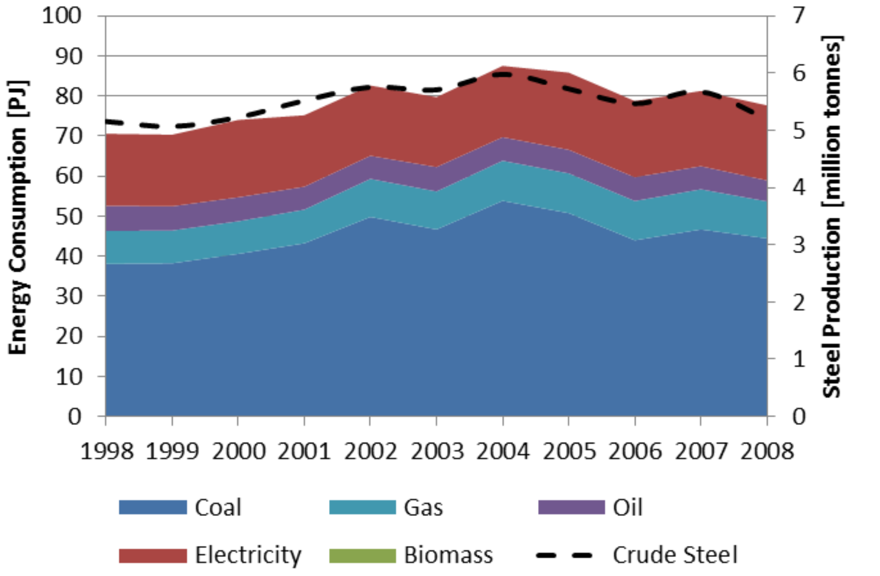

Figure 16: Energy use and steel production in the Swedish iron and steel sector, 1998-2008

Production and energy use

The Swedish iron and steel sector is diverse and includes both primary and secondary production. There are four major actors in the sector, three using EAF production and one using BOF, and several smaller companies focused on different niches. Focus in the Swedish sector is given to high-end products, such as high-strength and stainless steel, which can explain the relatively high average SEC in comparison with other developed countries. Swedish steel companies have large focus on increasing the quality of production and efficiency of the processes (Jernkontoret, 2009; Jernkontoret, 2011).

Sweden, as Brazil, has a large use of renewables in the iron and steel industry. The steel production is powered by primary renewable sources at a rate of 9 %. In Sweden, this share is due to the large renewable contribution to electricity production in the country. However, if the share of nuclear primary energy is added the total carbon-free sources amount to almost half of the energy demand for iron and steel production (see Figure 7). Direct use of renewables, biomass especially, is being discussed, but there is currently no direct use in the industries.

Regional trends and potential for improvements

There is large potential for reusing excess heat from the Swedish iron and steel mills. Martin & Setterwall (2008) made a first estimation in one Swedish steel plant. The authors found a potential of 1.5 TWh/year of excess heat which could be used for water and district heating from this plant alone. Johansson & Söderström (2011) also see potential for using excess heat, especially in iron ore based production plants due to the fact that there is a larger variety of energy flows in such a plant. The excess heat can be used to produce electricity using thermo-photovoltaics (photovoltaic diode cells adapted to produce electricity from the infrared part of the electromagnetic spectrum), or using hot water from cooling beds. Low-grade heat can be upgraded using organic ranking cycle to levels that allow electricity production, and thermal energy storage of excess heat can be used to transport heat and provide other energy services (e.g. district heating). Low-grade heat can also be used in industrial symbiosis, for example by transferring excess heat flows to other industries.

Johansson & Söderström (2011) also see potential for using excess gases (e.g. coke oven gases or blast furnace gases) for heat and power production, methanol production through methane reforming of coke oven gas, and DR steel production using coke oven gas. The authors also consider the use of biomass for iron ore reduction and fuel for heating furnaces as a means for reducing the environmental impact of steel production. However, using biomass as reducing agent in the iron ore reduction might not be cost effective and, in any case, a complete switch to biomass would require a large part of the Swedish bioenergy potential. Due to these barriers, the authors see the type of breakthrough technologies developed within the ULCOS program as more viable. Still, using biomass as fuel for heating furnaces is a realistic option which could contribute to lowering emissions when the technology becomes available.

In Sweden, attention has been given to energy efficiency in energy intensive industries through a government program that gives tax deductions in exchange for implementation of energy efficiency measures. After the first five year period, ending in 2009, electricity savings of 1.45 TWh/year was reported in the energy intensive industries due to the implementation of the program, far exceeding the target of 0.6 TWh/year set by the Swedish Energy Agency. A second period, lasting from 2009 to 2014, is on-going and a further continuation of the program is currently being discussed. Five companies involved in iron and steel production participated in the first period of the program, one mining company and four steel producers (Energimyndigheten, 2011b; Stenqvist & Nilsson, 2011).

Belgium

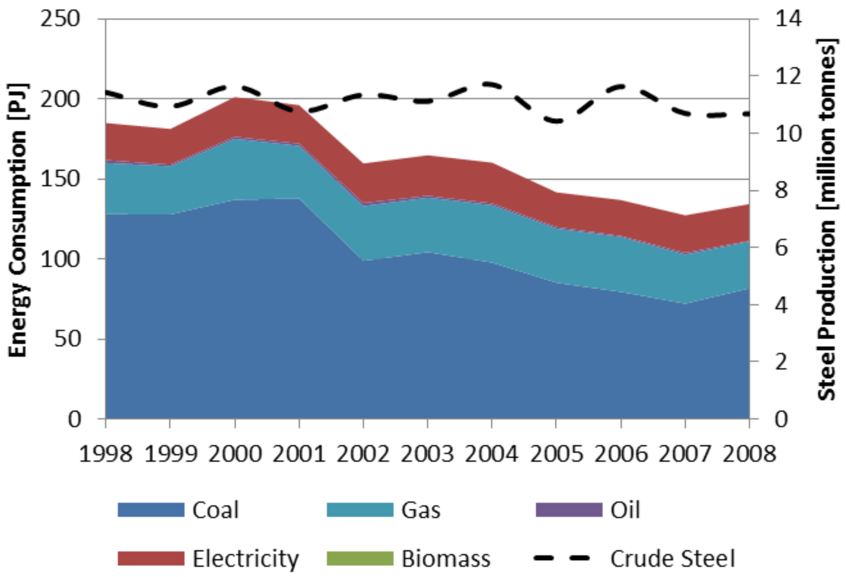

Figure 17: Energy use and steel production in the Belgian iron and steel sector, 1998-2008

Source: World Steel Association (2010) and United Nations Statistics Division (2011).

Production and energy use

The situation in the European countries is largely similar. Similar figures in steel use as well as energy intensity are found when comparing steel production in Sweden and Belgium. However, since the primary energy mix is different (electricity production being powered by nuclear and renewable energy sources to a higher degree in Sweden than other European countries), the environmental impact of production is still different. In Europe overall, the iron and steel production relies on fossil energy sources to 72 %, which is high compared to Sweden using about 53 % fossil energy (see Figure 7).

In Belgium, like in the US, there is a sharp decrease of energy use per tonne steel production (see Figure 17). The integrated steel plant in Ghent has a very high rate of injection of pulverised coal into the BF (up to 230 kg/tonne raw iron). Using injection of pulverized coal to large extent minimize the need coke demand. The current large use of pulverized coal provides an opportunity to move towards renewable resources since it is technically possible to supplement fossil coal with charcoal (Birat et al., 2008).

Regional trends and potential for improvements

The trend in Belgium is to improve the efficient use of energy and material flows. For example, convertor gases that are produced during the steel making process can be recycled, reducing the energy use by 4%. Hot charging can be used to reduce heating of the steel slabs to a minimum. Plans exist to increase the use of CO_2 from the blast furnace slacks to produce building materials.

Both Sweden and Belgium have slightly lower use of EAF than the European average. Shifting to EAF use could reduce the reliance on CO_2 emitting energy sources, especially in Sweden where the electricity mix is mainly based on renewable and nuclear energy sources. Improvements at the level of GHG emission follow the efforts to cut back the energy use. However, since cutting back the energy use has its limitations, there are serious plans for using CCS. The development of CCS plants depends not only on technological improvements but also on the development of the ETS.

3.6 Japan

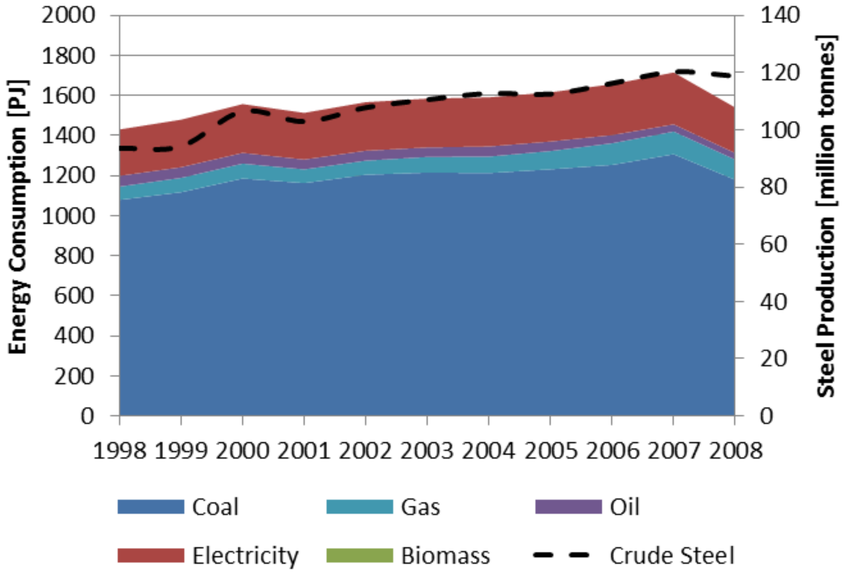

Figure 18: Energy use and steel production in the Japanese iron and steel sector, 1998-2008

Source: World Steel Association (2010) and United Nations Statistics Division (2011).

Production and energy use

Iron production in Japan is exclusively done in BFs. In 2010, 28 BFs were operational in Japan. Steel production is mainly done in BOFs (64 furnaces operational in 2010). However, in 2010, 347 EAFs were operational in Japan, mainly of small size (Japan Iron and Steel Federation, 2011).

The Japanese steel production relies to a high degree on imports. Iron ore and coal are imported. When it comes to iron ore the main suppliers are Brazil, South Africa and Australia. Furthermore, in total, over 80 % of Japans primary energy demand is covered by imports. This has provided incentives for researching and investing in energy efficiency improvements. Even though the Japanese crude steel is one of the most efficient in the world, it is carbon intensive. One reason could be that only a minor part of the Japanese crude steel production is based on the more energy efficient EAF process, see Figure 9. This might also be a reason why Japan is a net exporter of steel scrap (Lin et al., 2011; Japan Iron and Steel Federation, 2011).

Regional trends and potential for improvements

The Japanese iron and steel sector is one of the most efficient in the world. The industries have made large investments in energy efficiency improvements since the oil price shocks of the 1970s. Improvements have been made in continuous production processes, recovery of gases, recovery of excess heat, use of waste plastics, etc. The industry organisation, Japan Iron and Steel Federation (JISF), reports that Japanese energy efficient technology now is being transferred to emerging economies to facilitate the low-carbon steel making development. The JISF is also developing new low-carbon steel production technologies, using hydrogen as reduction agent and carbon capture and sequestration connected to BF processes (Japan Iron and Steel Federation, 2009).

It is worth noting that even though the Japanese iron and steel sector is energy efficient, it is still mainly reliant on coal as energy source. In 2008, only 25 % of the crude steel was produced using EAF, see Figure 9. Since Japan's electricity mix is based on nuclear and renewables to 34 %, a shift towards the EAF could help to reduce the environmental impacts of the Japanese iron and steel sector further (International Energy Agency, 2011b).

A project for the development of low-carbon steel making technologies was started in 2008. The project named COURSE50 (CO_2 Ultimate Reduction in Steelmaking Processes by Innovative Technology for Cool Earth 50) focuses on developing new or improved processes for greatly reducing the CO_2 emissions from steel production until 2050. The project includes technologies such as using hydrogen extracted from coke oven gas as a reduction agent, and to use excess heat for a carbon sequestration technique. Experimental plants are planned to be built in Sweden in cooperation with the company LKAB (Japan Iron and Steel Federation, 2011).

3.7 United States

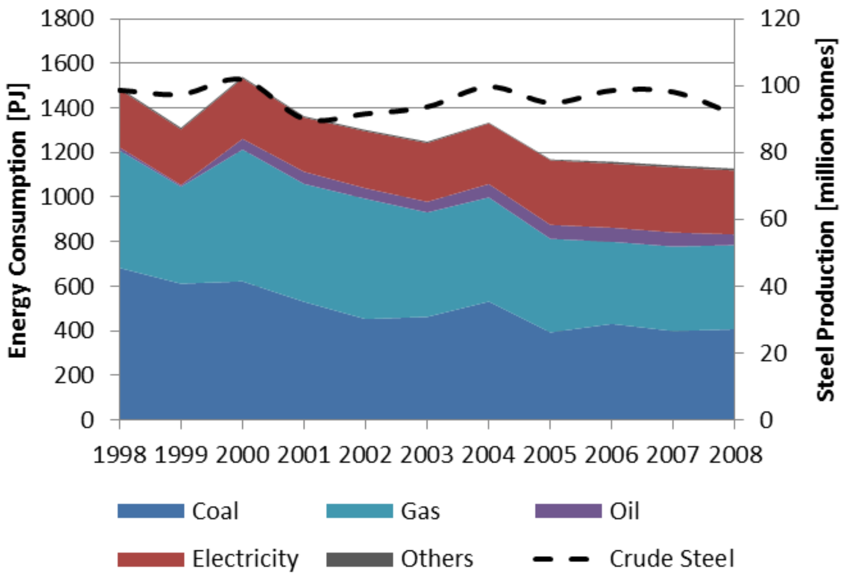

Figure 19: Energy use and steel production in the U.S. iron and steel sector, 1998-2008

Source: World Steel Association (2010) and United Nations Statistics Division (2011).

Production and energy use

The U.S. iron and steel production is concentrated to the Midwest and South parts of the U.S. The steel industry in the U.S. suffered from low profitability during the 1990's and early 2000's, but was revived when prices for steel started increasing a few years later. Steel production was also further supported by introducing temporary tariffs on imported steel in 2002. Despite the revival and increased stability of the U.S. steel industry, it is still vulnerable to international competition and the development in emerging economies, such as China. The reduction in energy intensity can partly be traced back to the restructuring of the industry during the last twenty years, which resulted in major consolidation in the sector, eliminating small and less efficient plants (U.S. Environmental Protection Agency, 2007).

The U.S. steel industry is focused on EAF steel making (see Figure 9). The use of EAF in the U.S. iron and steel sector is about 58 % and high-quality scrap is already being used to a high degree. EAF producers are actually investing in iron production facilities on-site as a supplement to scrap use, since there is a risk of scrap shortages (U.S. Environmental Protection Agency, 2007). In 2008, the U.S. used 66 Mt of scrap in its steel production, which corresponds as much as 72 % of the crude steel produced (Bureau of International Recycling, 2011).

The U.S. iron and steel sector has moved towards less energy intensive processes for steel production. Production in OHF was discontinued in 1992, mainly due to increased regulations on air-quality. The production was shifted towards BOF and EAF. EAFs are less energy intensive than other production routes and primarily use scrap as material input (Ruth & Amato, 2002).

Regional trends and potential for improvements

The U.S. Environmental Protection Agency (2007) identifies several opportunities for the U.S. iron and steel sector to reduce energy intensity and environmental impacts. For integrated steelmaking, the major opportunities are seen in integrating co-generation of electricity using off-gases from coke, and iron production with steel production. Also, there is potential for improving BF efficiency. For EAF production, the major opportunities are seen in improving the process efficiency, for example, increasing electrical energy transfer efficiency. For the industry as a whole, the report suggests further research into alternative processes for steel production with lower environmental impacts.

A program for identifying new technologies for further improving energy efficiency of steel production, increasing the U.S. industry competitiveness, and reducing the environmental impacts from steel production was launched in 1997 by the American Iron and Steel Institute and the U.S. Department of Energy. The final outcome, a technology roadmap, has identified a number of technologies which have the potential to reduce CO_2 emissions by 50% or more, much like the findings within the ULCOS program in Europe (American Iron and Steel Institute, 2010).

4 Challenges for European iron and steel industries

The iron and steel industry is a global industry. Traditionally, it has also been considered strategic due to its linkages with infrastructure development and many manufacturing sectors. Thus the European producers face competition around the whole globe. Industries in emerging economies such as China and India tend to have lower production costs not least due to the less stringent environmental policies applied in these countries. European policies for climate change mitigation in particular imply higher costs due to pricing of greenhouse gas emissions. Since these policies are regional, they tend to affect competitiveness in a business as usual context. This brings new concern about the future of the iron and steel industry in Europe.

A report developed for DG Enterprise and Industry in the EC indicates relocation to the east as a major threat to the European steel sector. In this context, China is seen as the most attractive country for relocation. But new developments are seen in other parts of the world as well. Already today, imports to Europe are common in certain iron and steel product segments. The present trend, with increasing stringency in environmental policy and intensifying competition at global level, is forcing the iron and steel sector to search for new strategies as a way to remain competitive (ECORYS SCS Group, 2008).

To survive in the global iron and steel market, the European industry has become more specialized in the past decades. Although the industry has capacity to produce all types of steel, the focus has shifted to high-quality products for specific uses and with higher value added. These products include high-strength and light-weight steel for manufacturing of transport equipment such as cars and air planes, as well as equipment for the energy sector such as wind mills. However, although steel demand continues increasing in Europe, new demand is largely met with imports rather than increased domestic production. As a result, the European industry has not only lost market share in the domestic market, but also in the export market (ECORYS SCS Group, 2008).

So the question is what is needed for the European iron and steel industry to be able to remain competitive in a global open market. In this report, we look at two key issues: technologies and policies. Technologies refer to opportunities to improve energy efficiency and reduce carbon emissions in iron and steel production. Policies refer to the need of incorporating the challenges of climate change in defining new strategies for the sector.

4.1 Opportunities for low-carbon iron and steel production

The iron and steel sector is far from a homogeneous industry, but has traditionally been a carbon intensive sector due to the nature of the processes involved and the large energy demands implied. In fact, the iron and steel sector is both energy and CO_2 intensive. In many regions energy efficiency improvements have already been implemented to a significant degree, for example in the E.U., the U.S. and Japan. However, it is important to remember that the multiple players operating in the industry apply different technologies, inputs and processes, and the term *iron and steel* actually encompasses different output – products and services with varied quality and characteristics. Moreover, the various phases of production may be organized in geographical constellations that imply different levels of environmental impact. This calls for new innovative solutions to steel production accommodating increasing demand for a greener steel production with lower climate change impact, and also new ways of integrating the various phases of production.

It is in this multi-dimensional context that opportunities for process shifts, energy efficiency improvements and emissions reductions need to be evaluated. In addition, the geographical spread of the industry has implications on the logistics of transport, that too having implications for the total impact on the footprint of the industry – an aspect that has not yet been properly explored. There is high energy content and costs related to transportation of commodities within the industry which need to be addressed as part of efforts to reduce the total impact of the sector (Yellishetty et al., 2010; ECORYS SCS Group, 2008). Finally, integration with other industries and service functions need to be explored, evaluating life-long impacts of products and applications.

When it comes to processes, the European Commission is supporting a major research program focused on Ultra Low CO_2 Steelmaking (ULCOS). The ULCOS program aims to reduce the CO_2 emissions from steelmaking by 50 % compared to the current best-practice. The measures identified by the project are expected to be implementable in a 15-20 years period. ULCOS covers a large consortium of actors in the European iron and steel sector and is run by ArcelorMittal. The first phase (ULCOS I) ended in 2010 resulting in a number of identified opportunities to improve and refine the transformation processes applied in the industry. Breakthrough technologies in the program are the following (Birat, 2009; Birat et al., 2008; Croezen & Korteland, 2010):

- **Top gas recycling (TGR)** in BFs, which is a technology where the top gas from a blast furnace is recycled and reused in the furnace. The gas can also be CO_2 scrubbed for storage of the CO_2 in the gas. CO_2 emission cuts of 65 %, when using storage, and 15 % when no storage is used, are indicated by ULCOS. This technology is seen to be close to implementation and a demonstration is planned within short.
- **HIsarna** is a technology using smelting reduction, where the coke-making process is eliminated. The HIsarna concept combines several process steps and a potential emission reduction of 20 % is indicated. Combined with CO_2 capture and storage the emission reduction is indicated to become about 80 % compared to BF. This technology is also close to implementation and demonstration plants are planned for the short-term.
- **ULCORED** is a technology for direct iron reduction using natural gas, producing hydrogen as a by-product. Potential emission reductions of about 50 % compared to the present route is indicated and also for this route the demonstration plants are planned in the short-term.
- Iron ore **electrolysis** has also been investigated, but the technology is not yet mature enough for pilot or demonstration projects. Further research on this technology will be carried out within the scope of the ULCOS program.
- Potentials for steel production using **biomass** and **hydrogen** have been shown, but these development paths have not been chosen as focus for the ULCOS project. One reason for this, as indicate by Croezen & Korteland (2010), is that the sustainable production of biomass has not been verified.

In addition to the process improvements listed above, there are other ways of increasing energy efficiency and reducing the environmental impacts from steel production. This includes increasing the amount of scrap used in steel production, using excess heat in other industries and district heating, and improving the value chain of steel production as a whole. This requires cooperation between iron and steel industries and other industries or public actors. In some cases, the regulations are not in place to enable this cooperation.

For example, increasing the amount of scrap in steel production requires actions not only from the iron and steel industries, but from several other sectors. The scrap provided within factory gates and from some manufacturing industries is already used to a high degree. The large scrap potential lies in the *old scrap*, the scrap originating from end-of-life of steel products. This scrap is, however, more difficult to collect and cooperation between several actors along the value chain of steel production is required to increase recycling.

Thus the iron and steel producers are developing new and greener production methods to reduce the environmental impact of steel production. There are concrete opportunities for further reduction of energy demand and greenhouse gas emissions in the sector. The question is how to take these technologies from research and development phases towards full implementation and commercialization. The shift from the production methods of today will require both time and major investments. It is, therefore, important to assess and understand the long-term benefits of shifting methods to provide support for the decisions required to change the industry's structure.

4.2 Climate change mitigation

One of the reasons for the increased pressure on European industries is related to the targets set up by the European Union for reduction of greenhouse gases. In the iron and steel industry, this translates into targets and caps on CO_2 emissions especially. The industry is included in the EU Emission Trading Scheme (ETS) (ECORYS SCS Group, 2008). However, the industry has been quite negative to the continuation of the scheme claiming that it is damaging the competitiveness of the European industry. The industry's perception is that climate change measures need to be global to be effective in mitigating climate change. In addition, given the global character of the industry, material imports and high energy use imply large amounts of embedded energy in the products traded that are not being accounted for.

Several studies have investigated the impact of the EU ETS on competitiveness and found that the negative impacts claimed by the industry are not well founded. In fact, the profitability in the iron and steel sector could have actually increased during the first phase of the EU ETS due to opportunities to generate and sell emissions allowances. In the following phases the losses are expected to be modest in the sector. At an allocation of 50 % compared with the business-as-usual scenario (i.e. the sector is provided with emission allowances for free equivalent to 50 % of the emissions shown in the business-as-usual scenario) the profits are only reduced by 3 %, which is within the range of common market fluctuations (Demailly & Quirion, 2008; Quirion, 2002; Quirion & Hourcade, 2004).

Meanwhile, other regions have decided to implement or are discussing the implementation of ETS. In New Zealand an ETS has already been established. In California, United States, the decision to implement an ETS has been taken and is planned to start in 2013. In China there is an on-going discussion on implementing pilot schemes in several regions. The regional Chinese schemes are expected to start before 2013, and a national system is thought to be ready for implementation in 2015. In South Korea the implementation of an ETS is being discussed, although industries strongly oppose the system and this could delay the start scheduled for 2015 (Carroll et al., 2011; Stanway & Lane, 2011; The Ministry for the Environment, 2012; Mee-Young & Fogarty, 2011). In any case, regional ETS regimes are being established all over the world, and are likely to gradually become integrated into a global market mechanism serving to internalize carbon costs and promote innovation.

The issue of carbon leakage is nevertheless a major issue for policy makers, companies and society at large. Policy makers aim to internalize costs through implementing environmental policies and the ETS has proved effective in helping the EU reach emissions reduction targets. In particular, the ETS has been very effective in addressing electricity generation, a sector that is somewhat geographically protected from carbon leakage due to technical constraints on electricity imports. Manufacturing industries which are exposed to international competition such as the iron and steel sector could be more exposed if producers and markets are segmented within very different regional environmental and climate policies (Clò, 2010). Thus different system boundaries are worth exploring, within which to evaluate the overall impact of the iron and steel industry on climate change.

The EU ETS can be seen as having a production-based allocation method. It assigns the responsibility to the producer and expects the producer to internalize the costs of the emissions in the final price. Several authors suggest that a consumption-based allocation method would be more reasonable and reduce the risks of carbon leakage (Peters & Hertwich, 2008; Clò, 2010; Peters, 2008; Lenzen et al., 2004; Wagner, 2010). Finding a method for consumption-based allocation is difficult and there is a risk of creating a black box for calculating the emissions of products on which the internalized cost is based. Such a system would be less transparent and possibly difficult to implement. In any case, the discussion indicates the need to find a system that better reflects the characteristics of the iron and steel sector.

In the new ETS directive a new allocation method is proposed to minimize the risks of carbon leakage. Sectors exposed to carbon leakage will be exempted from the auctioning principle and continue to receive free allowances. However, Clò (2010) has identified several drawbacks of this approach. The directive neither specifies on what benchmark the free allowances should be allocated nor indicates on what level of aggregation the sectoral carbon leakage risk should be assessed. There is a risk such an allocation system could also become a black box, making it difficult for industries to understand and comply.

The new directive and allocation system could provide some relief to the most exposed sectors. But it does not resolve the problem of embedded energy and environmental impacts resulting from trade flows. A global ETS would solve this issue, but may take some time to be put in place. Thus different policies need to be devised. One consumption-based method being discussed is border carbon adjustments, which puts a tax (or requirement to buy emission allowances) on imports of products related to the sectors in the ETS. Such a scheme would not only reduce the risk of carbon leakage, but also provide an incentive for industries trading with areas covered by the ETS to eventually reduce their own CO_2 emissions. However, such a system is also contentious as it is often understood as violation to WTO rules, with high welfare costs particularly in developing countries (Fischer & Horn, 2010; Winchester et al., 2010).

The European Union Emission Trading System (EU ETS)

Emission trading is one of the market-based mechanisms created to promote climate change mitigation under the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC). The implementation of the concept was first introduced in the European Union in 2005 through the EU ETS. After a first three-year trial period it has now gone into its operative phase. The system covers heat and power producing industries as well as selected energy-intensive industrial industries, namely combustion plants, oil refineries, coke ovens, iron and steel plants and factories making cement, glass, lime, bricks, ceramics, pulp and paper. From 2012, the aviation sector is also included in EU ETS. The system is active in 30 countries in total: the 27 EU member states, Iceland, Lichtenstein and Norway (European Commission, 2008).

The EU ETS is based on the concept of ‘cap-and-trade’. One allowance is equivalent to emitting one tonne of CO_2. The allowances are allocated to companies inside the EU ETS region through national allocation plans. During the first period (2005-2007) almost all allowances were allocated for free, but as the EU ETS entered the second period (2008-2012) and prepares for the third period (2013-2020), free allocations have been reduced gradually. For companies this means that, if they are unable to reduce their emissions, they will be forced to buy allowances from companies that did lower their emissions or from companies active in CDM or JI activities in which carbon certificates are generated. If a company does not acquire enough allowances to cover its emissions, it will incur a penalty charge of 100 EUR per tonne of CO_2. This charge will be increased with the rate of inflation in the Eurozone after 2013. According to calculations by the European Commission, the system is actually working towards lowering emissions. In 2010, the average emission per installation had dropped by 8.3 % compared to 2005, when the system was introduced (European Commission, 2011).

The EU ETS directive has undergone a revision for its last implementation period (2013-2020). Carbon leakage is defined as the increased emissions in countries outside an ETS region divided by the reduced emissions inside the ETS region (Barker et al., 2007). To address this issue and the risk of carbon-intensive industries relocating to regions with fewer restrictions on CO_2 emissions, the revision resulted in three ways of allocating allowances depending on how exposed the sector is to carbon leakage. Energy producing industries will go to full auctioning in 2013, which means that they will not receive any free allowances. For other sectors the amount of free allowances will be gradually reduced. The possibility to exempt sectors exposed to high carbon leakage is introduced as a third option. Exempted sectors will receive free allowances, but not according to historical emissions (as was the principle in the first periods of the EU ETS), but according to a best practice benchmark. The benchmark is, however, yet to be determined (Clò, 2010).

5 Actions for change

If the European iron and steel sector is to remain competitive, new approaches will be needed in the way the industry defines its strategies. Being the second largest consumer of energy and with products on high demand, the iron and steel industry will have to devise ways to further improve energy efficiency and reduce greenhouse gas emissions. Innovation will be needed in the processes used but this will not be enough. The industry will have to innovate also in the way it addresses its supply-chain as well as in the way it defines its forward linkages along other production lines. A system approach embracing the new challenges implied in stringent environmental requirements will be key to guaranteeing competitiveness.

Analysing competition within a narrow context may not be to the advantage of the European industry. The products being traded have embedded environmental costs which are not being incorporated in a homogeneous way around the globe. There is, therefore, on the one hand strong pressure to promote technological change and, on the other hand, define methods that better account for environmental impacts wherever they take place.

Implementing measures that capture impacts at a global level without harming trade and welfare is a challenging task. Policy makers and industries need to work towards incremental changes and common goals. Climate change could provide the overarching common goal necessary to catalyse change, but so far, climate policies and mechanisms have been difficult to implement simultaneously at global level. Finding ways of capturing the benefits of efforts being made by the industry, and reshaping markets towards sustainability is to the interest of European industries and society at large.

Actions are required from multiple stakeholders, including steel producing companies and other industries connected to the value chain of steel products. Governments need to provide incentives and effective regulatory frameworks to encourage and support innovation and technological shifts. In other words, a conducive policy environment will be required, including regulations and standardisations, but also incentives and a review of market structures under which the environmental performance of the iron and steel industry is to evolve in a global order towards sustainability. Iron and steel producers must be able to trust long-term policies when deciding on new investments, but also need to review their own strategies within the new market order.

A broader system boundary allows seeing the full costs and benefits of the iron and steel industry. In particular, it puts the climate impacts of the industry in relation to other value chains and a broader industrial perspective. New methodological approaches are needed to actually implement such an approach. There is need for in-depth analyses of the environmental impacts of innovative steel production processes integrated with other functions along the value chain, better understanding of the future steel demand taking into account global perspectives, and planning and monitoring of regional impacts to guarantee welfare. These analyses are required to support the decisions of various stakeholders and ensure the development of a strong European iron and steel sector under climate change mitigation constraints.

In this context, ESA^2 can contribute with a varied tool-box for assessment of changes in the iron and steel sector. In addition to the above mentioned areas of interest, there is current need for better data on energy use and efficiencies, GHG emissions and industrial structure of various regions. Such database will allow the development of better account systems for embedded energy and greenhouse gas emissions. Larger insight in the global development of the iron and steel sector can provide important details on the environment that the European industries are competing in.

ESA^2 bases its services on the knowledge and experience of 13 research groups/companies in the field of energy systems analysis. ESA^2 can provide industries with in-depth analyses to support strategic investment decisions. ESA^2 can also provide the EU and national governments with assessments of the impacts of different policy options. Finally, ESA^2 contributes to ensure a sustainable development for European industries.

ESA^2 Pilot project
Scenarios for Energy Intensive Industries – Low Carbon Steel

A pilot project is being developed focused on low carbon steel production in the E.U., China and Brazil. The project aims to analyze how low carbon steel production can help meet the targets set up by the EC (a 30% reduction compared to 1990 emissions in the EU by 2030 and 80% reduction by 2050). The world energy model ETSAP TIAM will be used. The model has an explicit representation of all the steel producing technologies with impact on the carbon balances. The report will highlight the most promising technologies, impacts on steel prices, expected steel capacities in different regions of the world in scenarios up to 2050. The pilot project will combine the large knowledge-base and experience provided by the different research groups participating in ESA^2. More information on the pilot project will be available at www.esa2.eu.

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Our approach is comprehensive model-based decision-support offering one-stop-shop solutions to government organizations, NGOs and companies when defining development strategies, efficiency improvements or investment decisions within changing policy frameworks.

We use a flexible tool kit of well-known models and approaches linked to a common data base, taking into account the tensions between local or company related interests and international and national societal objectives and macroeconomic goals.

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- processing useful information and timely making it available for clients to support their strategic business or political decisions;
- identifying market potential for new technologies, green twinning or by-product synergies, and potential projects with climate benefits, and finding partnerships for their implementation;
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- overcoming barriers in markets for new technologies and products;
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