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The iron and steel industry: a global market perspective

Introduction

The iron and steel industry is a very complex sector which is intrinsically linked with the world economy as a whole. Steel products are needed by many industries, such as automotive, construction, and other manufacturing sectors. The steel industry uses significant amounts of raw materials (mainly iron ores, coal and scrap) and energy, and is also a major source of environmental releases such as (among others) emissions of dust, heavy metals, sulphur dioxide, hydrochloric acid, hydrofluoric acid, polycyclic aromatic hydrocarbons and persistent organic pollutants from sinter plants and coke ovens; waster water from pelletisation; dust and waste water from blast and basic oxygen furnaces; or emissions of filter dust, slag dust, and inorganic and organic compounds from electric arc furnaces (European Commission. 2011). Most raw materials are located remote from the areas of highest steel demand, and so both steel products and inputs are traded internationally and in large quantities. This trade is carried out mostly by sea-going vessels, with raw materials flowing from coal and ore-rich producing countries in South America, Africa and Oceania to major producing areas in Europe, North America, and the Far East, followed by shipments through rail and inland waterways, and semi-finished and finished steel products moving in the opposite direction. That has a particular impact on supply and demand patterns, and consequently on prices.

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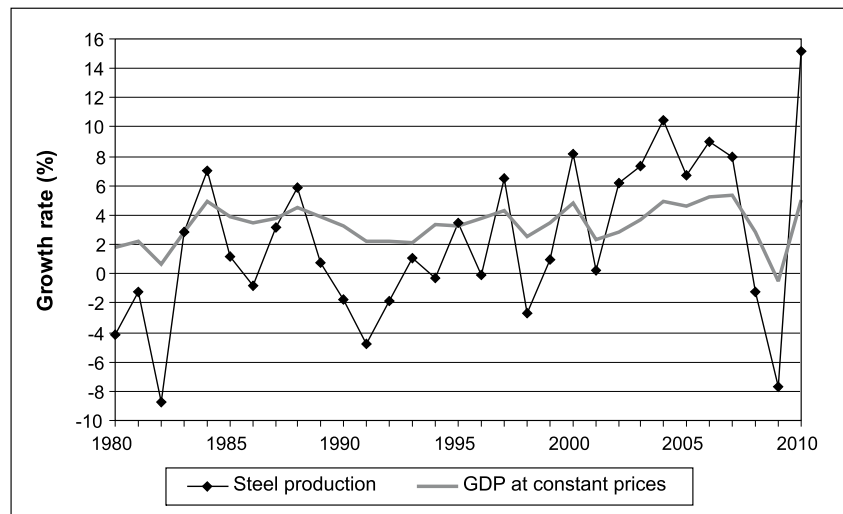
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Fig. 1. World steel production and GDP growth rates
Source: (www.worldsteel.com and www.imf.org)

Rys. 1. Tempo wzrostu światowej produkcja stali oraz PKB

The steel industry consists of some large firms that operate globally and have a significant output, and many small firms that operate at a lesser scale. Recently, some of those firms have consolidated into large multinationals (such as ArcelorMittal, formed in 2006 by the merger of Arcelor and Mittal Steel, Arcelor being the result of the previous merger of Aceralia (ES), Usinor (FR), and Arbed (LX) in 2002, see section 2 for more details on the consolidation of the steel industries). The industry has been the subject of oligopolistic analyses since the 50s to date, either concentration index-based (Herfindahl 1950; Lee 2011), or model-based (Warrell, Lundmark 2008). However, despite the recent consolidation trends towards multi-national companies, those analyses focus on specific countries and regions.

The aim of this paper is to provide an overview of the iron and steel industry, focusing on steelmaking technologies and international steel markets. The results of this paper will form the basis for further long- and mid-term analyses of the development of the global steel industry.

To this purpose, section 1 describes how steel is currently produced, section 2 shows the main characteristics of the steel markets, and section 3 concludes with some recommendations for further research.

1. Steelmaking technologies

Steel is a class of malleable alloys made up of iron and carbon (less than 2%), plus some other additives in small amounts (with proportions ranging widely from less than 1% for low alloy steels to more than 10% in the case of stainless steel or special steels for tools). Thus,

there are many grades of steel (more than 3500) differing in composition and physical and chemical properties (Fenton 2005). Steel is one of the most important materials in the world, with applications in virtually all construction, manufacturing, and engineering-related fields.

Steel is produced by melting iron (in form of pellets, sinter, or DRI) and reducing its content of carbon down to the desired level. There are two basic production methods that account for most of the production (Worldsteel 2008):
— primary steelmaking (~72% of the global production),
— secondary steelmaking (~28% of the global production) (Worldsteel 2010).

Within the primary methods there are four possible production routes available at industrial scale, depending on the equipment used and on the region considered (Worldsteel 2010; Yellishetty, Ranjith, Tharumarajah 2010):
— a combination of a blast furnace (BF) with a basic oxygen furnace (BOF) (which accounts for ~64% of the world total production),
— a blast furnace with an open hearth furnace (OHF) (~1% of the global total),
— a direct reduction unit (DR) with an electric arc furnace (EAF) (~6% of the world total),
— a smelting reduction unit (SR) with a basic oxygen furnace (less than 1% of the world total).

Primary steelmaking involves up to four major steps which require large facilities:
1) mining and preparation of raw materials,
2) iron production,
3) steel production,
4) casting, rolling and finishing.

The main raw materials are iron ore, coal, limestone, scrap and energy. Approximately 95% of the energy input consists of solid fuels (mainly coal), ~3% of gaseous fuels, and ~2% of liquid fuels; electricity input is much smaller (Worldsteel 2008).

The secondary method produces steel by recycling used steel products and ferrous scrap in electric arc furnaces. Secondary steelmaking usually involves stages 3 and 4. The main inputs are scrap and electricity.

1.1. Mining and preparation of raw materials

The first step to produce steel by means of a primary steelmaking method consists of the mining and preparation of raw materials. The most important raw materials are iron ore, coke, limestone, and ferrous scrap. Iron ore is mostly obtained from open cast mines, then crushed and concentrated into pellets (small iron ore balls) or sinter (iron ore lumps baked with coke or coal). Iron ore is mined in about 50 countries, the majority originating from Brazil, Australia, China, India, the US and Russia. Australia and Brazil accounting together for about one third of total world exports (Worldsteel 2010). Iron mines are often remote from steel mills, so iron ore needs to be transported by rail to dedicated port terminals,

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and then shipped in bulk carriers to steel producing locations (Yellishetty, Ranjith, Tharumarajah 2010).

Coking coal is mined from open cast or underground mines, washed, and converted into coke (almost pure carbon resulting from conversion of coal without oxygen at high temperatures). The quality of the coking coal, or rather a specific mixture of selected coals, directly influences the final coke quality. In fact the coke quality is more dependent on the coal mixture than on the coke production technology. As a result, prices of selected coking coals (premium hard, hard) are significantly higher than prices of semi-soft coals (even by 30–50%). Coke producers are usually located in the steel producing regions. In 2007 the Asian countries produced 406.5 Mt of coke out of the world total 554.2 Mt, with China being the biggest producer (329 Mt of coke (recalculated for dry coke)). Poland and Germany are the main EU coke producing countries with annual production of 10.3 Mt and 8.10 Mt respectively (Ozga-Blaschke 2010).

Scrap iron consists of steel and ferrous products at the end of their lifetime (obsolete scrap), steel discarded during the manufacturing processes (prompt scrap: by sector, steel recovery rates can be estimated at 85% for construction, 85% for the automotive industry, 90% for manufacturing of machinery, and 50% for electrical appliances), or any scrap generated within the steel industry and immediately fed back into the steelmaking process (home scrap). The availability of home and prompt scrap is related to current production levels, while the levels of obsolete scrap depends on past steel production, average product lifetimes, and recycling rates (Worldsteel 2011).

Limestone is used in the furnaces to form slag (a by-product resulting from impurities and non-metallic inclusions into the steelmaking processes, which may be used in the production of concrete in combination with Portland cement). Other additives like metals, plastics and heavy oil may be used in the different production phases.

1.2. Pig Iron Production

In the second step, hot metal (or molten iron, also known as pig iron when solidified) may be produced by two means:
— either charging iron ore and coke to a blast furnace,
— by reducing iron ore with natural gas or low quality coke (this can be done in direct reduction units, which may be shaft furnaces, rotary kiln furnaces, or fluidized beds).

The blast furnace-based process uses sinter, pellets, lump ore and coke. All the inputs are charged to the top of the furnace, and heated to remove oxygen from the iron ore and produce the hot metal.

The direct reduction process uses pellets, lump ore, and natural gas (or low quality coke) to reduce the iron ore. Pellets and lump ore are heated under pressure in the presence of natural gas and reduced to DRI (direct reduced iron: pelletized iron).

1.3. Steel Production

In the third phase the steel is produced by oxidizing the hot metal (or direct-reduced iron (DRI)). There are three possible furnaces to produce the steel:
— open hearth furnace (OHF),
— basic oxygen furnace (BOF),
— electric arc furnace (EAF).

The BOF is a vessel where oxygen is injected into the hot metal to remove carbon and other impurities. The BOF can take a mixture of hot metal, scrap and DRI. The OHF is similar to the BOF, but much slower and with a higher energy input, and therefore is not competitive with the BOF and has become obsolete. In these two furnaces, the energy that drives the steelmaking process comes from the heat of the hot metal charge and from the combustion of the contained carbon. The EAF can take a full charge of scrap or DRI (mixtures are also possible), and requires electricity to melt the cold charge.

1.4. Casting, rolling and finishing

During the fourth step, once the crude steel is produced by any of the processes described above, it is transferred to an ingot casting shop (where ingots are produced in batches by pouring steel into moulds) or to a continuous casting shop (where liquid steel is poured continuously and then cut into the desired shapes). The semifinished products obtained from the casting processes are ingots (blocks), slabs (a length of metal with rectangular cross-section), billets (a length of metal with round or square cross-section), or blooms (similar to billets, with greater cross sectional area). These semifinished products are later rolled into different shapes. Slabs are converted into thinner steel plates (flat products) in plate mills or hot strip mills. Other finished shapes (long products) are rolled from blooms and billets into beams, reinforcing bars, and wire rods through different types of mills. Further treatments (coating, annealing, galvanizing, tinning, etc.) are provided in specific finishing mills.

Figure 2 shows a sketch of the primary and secondary steelmaking methods outlined previously.

1.5. Energy use and emissions

The steel industry is highly energy-intensive and very dependent on the use of fossil fuels. At the global level, energy flows within the iron and steel industry are rather complex, since energy is simultaneously converted (e.g. from coking coal into coke) and consumed by the steel production processes. In Table 1, the first two columns show the transformation components of the steel industry's energy balance in 2006. Globally, blast furnaces consumed 13.58 Mtoe of coal and peat, and 3.23 Mtoe of petroleum products, and generated 10.69 Mtoe of gas products which were usually re-used somewhere else within the steel industry.
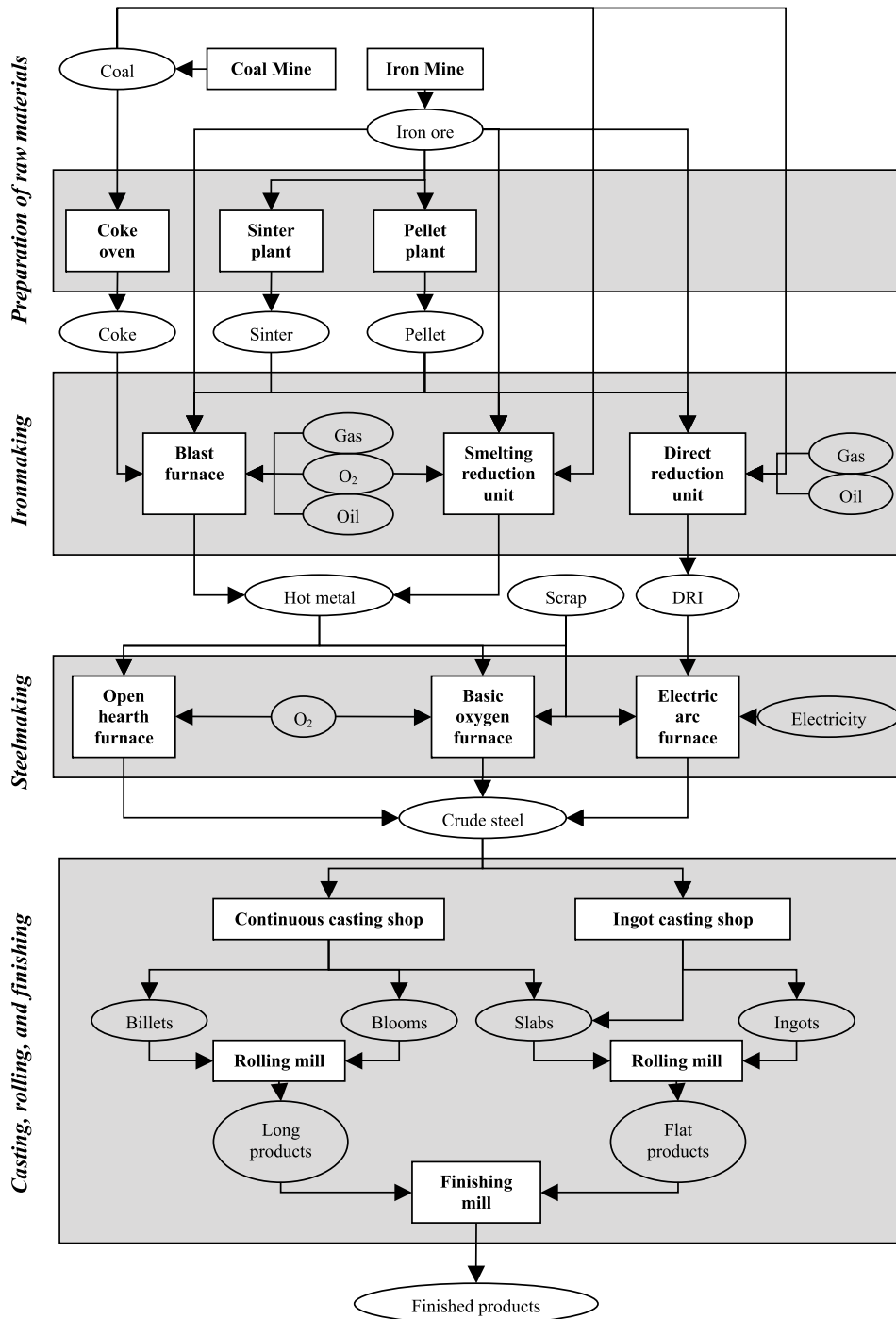
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Fig. 2. Steel production routes

Rys. 2. Ścieżki procesu produkcji stali

The transformation of coking coal into coke required the consumption of 187.56 Mtoe of energy inputs, mostly coking coal. The rest of the steel production processes required an energy input amounting to 384.64 Mtoe in 2006, most of which consisted of coal and peat (54.27%), electricity (22.08 %), and gas (14.90%) (fuel categories as defined by the IEA (IEA 2008).

<div align="right">TABLE 1</div>

Global energy balance of the iron and steel industry in 2006

<div align="right">TABELA 1</div>

Globalny bilans energii produkcji żelaza i stali w 2006 r.

Fuel	Energy supply[A] (Mtoe)		Final consumption[B]	
	Blast furnaces and gas works	Coal transformation[C]	Mtoe	%
Coal and peat[D]	–13.58	–184.6	208.75	54.27
Crude oil[E]	0.00	0.02	0.01	0.00
Petroleum products[F]	–3.23	–2.8	14.81	3.85
Gas[G]	10.69	–0.17	57.32	14.90
Renewables and waste	0.00	–0.01	6.2	1.61
Electricity	0.00	0.00	84.92	22.08
Heat	0.00	0.00	12.62	3.28
Total	–6.12	–187.56	384.64	

[A] – Production plus imports minus exports, plus stock changes.

[B] – This column includes final energy consumption due to all activities under ISIC's (International Standard Industrial Classification of All Economic Activities) Group 271 and Class 2731. More details about the ISIC registry system are available at http://unstats.un.org/unsd/cr/registry/isic-4.asp.

[C] – Coal transformation contains losses in transformation of coal from primary to secondary fuels and from secondary to tertiary fuels (hard coal to coke, coke to blast furnace gas, lignite to BKB (brown coal briquettes), etc.). It is often difficult to correctly account for all inputs and outputs in energy transformation industries, and to separate energy that is transformed from energy that is combusted. As a result, in certain cases the data in the total column are positive numbers, indicating a problem in the underlying energy data. Coke/patent fuel/BKB plants covers the use of fuels for the manufacture of coke, coke oven gas, patent fuels and BKB.

[D] – Includes all coal, both primary (including hard coal and lignite/brown coal) and derived fuels (including patent fuel, coke oven coke, gas coke, BKB, coke oven gas, blast furnace gas and oxygen steel furnace gas). Peat is also included in this category.

[E] – This row comprises crude oil, natural gas liquids, refinery feedstocks, and additives as well as other hydrocarbons (including emulsified oils, synthetic crude oil, mineral oils extracted from bituminous minerals such as oil shale, bituminous sand, etc., and oils from coal and gas liquefaction).

F – Petroleum products comprise refinery gas, ethane, LPG, aviation gasoline, motor gasoline, jet fuels, kerosene, gas/diesel oil, heavy fuel oil, naphtha, white spirit, lubricants, bitumen, paraffin waxes, petroleum coke and other petroleum products.

[G] – This row includes natural gas (excluding natural gas liquids) and gas works gas. The latter appears as a positive figure in the "gas works" row but is not part of production.

Source: IEA 2008.

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With this energy mix, the iron and steel industry is also a major source of greenhouse gas (GHG) emissions and air pollution. Global direct CO_2 emissions from final energy consumption in the iron and steel industry amounted to 1035.39 Mt CO_2 in 2006, i.e 3.70% of total CO_2 emissions from fuel combustion. Direct emissions are calculated from the figures presented in Table 1, multiplying the final consumption levels by the appropriate carbon content (expressed in tC/TJ: 25.8 for coal and peat, 20 for crude oil and petroleum products, 15.3 for gas, and 29.9 for renewables and waste) and conversion factors (1 Mtoe = 41868 TJ); electricity-related and process emissions from BF and coke oven plants are not included in the estimation. Most of the emissions were caused by the use of coal (826.80 Mt CO_2), then gas (134.63 Mt CO_2), petroleum products (45.47 Mt CO_2), and solid biomass (28.46 Mt CO_2).

Note that in Table 1 the column "blast furnaces/gas works" covers the quantities of fuels used for the production of town gas, blast furnace gas (BFG) and oxygen steel furnace gas (BOFG). The production of pig iron from iron ore in BF needs the use of solid fuels for physically supporting the blast furnace charge and providing heat and carbon for the iron reduction process. Accounting for the calorific content of the fuels entering the process is a complex matter as transformation (into BFG) and consumption (heat of combustion) occur simultaneously. Some carbon is also retained in the pig iron; almost all of this reappears later as BOFG (or converter gas) during the steelmaking phase. In principle, the quantities of all fuels entering BF and the quantity of BFG and BOFG produced are collected in the energy statistics. However, most of this data is frequently reported as being uncertain or incomplete. IEA splits these inputs into the transformation and consumption components. The transformation component is shown in the column "blast furnaces/gas works" in the row appropriate for the fuel, and the consumption component is shown in the column "final consumption" in the row appropriate for the fuel. It is assumed an 80/20 split of coke oven coke between the transformation and consumption components (IEA 2008).

Energy intensity depends on the steelmaking process used, the characteristics of the raw material inputs, and the grade of the steel produced, and also differs between facilities with different degrees of energy and material efficiency. Table 2 shows typical ranges of energy intensity and raw material inputs per ton of crude steel by production route (all steps but mining are included).

Primary steelmaking is more energy-intensive than secondary steelmaking; although the by-product gases from coke ovens, blast furnaces, and basic oxygen furnaces can be fully reused (those gases contribute up to ~40% of the energy input, and are used to replace other fuels or to generate electricity). Secondary steelmaking does not need that amount of energy per ton of steel, but there is not enough supply of scrap to significantly increase the share of this production method in the world total.

Steelmaking technologies have not changed fundamentally in the last decades. However the steel industry has carried out significant work to optimize production at various stages, improve energy efficiency, and reduce emissions. The result is that energy intensity has been reduced approximately by half in the last 40 years. The challenges posed by climate change

TABLE 2

Energy intensity and main raw material input ranges

TABELA 2

Energochłonność i zużycie kluczowych surowców mineralnych w procesie produkcji stali

Production route	Energy intensity [GJ/t CS[A]]	Iron ore [t/t CS[A]]	Coal [t/t CS[A]]	Limestone [t/t CS[A]]	Scrap [t/t CS[A]]
BF-OHF	26.4–41.6	–	–	–	–
BF-BOF	19.8–31.2	1.495–1.620	0.222–0.770	0.030–0.158	0.120–0.424
SR-BOF	30.4–32.1	1.490–1.780	0.630–1.200	0.006	–
DR-EAF	28.3–30.9	1.700	–	–	–
EAF	9.1–12.5	0.000–0.368	0.005–0.034	0.025–0.140	1.039–1.232[B]

[A] – crude steel; [B] – or DRI
Source: ETSAP 2010; European Commission 2011; Worldsteel 2008; Worldsteel 2011.

issues and the new environmental legislation that is coming into force (such as the emission trading schemes) is fostering research aimed at overcoming the limitations of conventional steelmaking technologies and at identifying new technologies able to produce much larger reductions in GHG emissions. Currently there are several regional research initiatives throughout the world, such as the AISI Technology Roadmap Programme in the US (http://steeltrp.com/), the Ultra-Low Carbon Dioxide Steelmaking (ULCOS) project in Europe (http://www.ulcos.org), the POSCO CO_2 Breakthrough Framework in Korea (http://www.posco.com/), or the COURSE50 programme in Japan (http://www.jisf.or.jp/). Those initiatives involve steel producers, energy suppliers, and engineering firms. The most promising results of those initiatives focus on:

— in-process CO_2 capture (by using modified BFs or smelting reduction processes),
— use of hydrogen as a reducing agent,
— use of electricity as a reducing agent,
— use of biomass to produce reducing agents,
— carbon capture and storage (CCS) (Worldsteel 2009).

2. Steel markets

2.1. D e m a n d

Steel consumption is commonly linked to GDP per capita levels through the so-called steel intensity, which can be described as a function that, although depends on the country considered, usually follows an inverse U-shaped curve (Mannaerts 2000; van Vuuren,
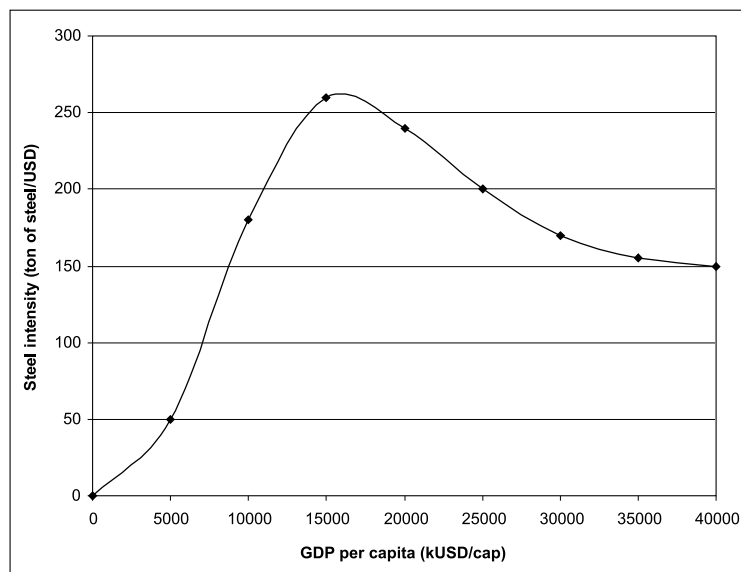
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Fig. 3. Typical steel intensity curve with respect to GDP per capita

Rys. 3. Typowa krzywa konsumpcji stali w zależności od PKB na mieszkańca

Strengers, de Vries 1999). That shape can be explained by the overlapping of three different effects in the requirements of steel produced by:
— changes due to the economic transition from agriculture-manufacturing and building--services,
— changes due to substitution by competing materials,
— changes due to technological developments – developing countries would be by the left side of the curve, while developed countries would be by the peak or the right side.

Steel products are used for a wide range of applications in which there is not a suitable alternative, such as buildings and infrastructure, machinery and equipment, tools, appliances, weaponry, and ships and vehicles. Around 25% of the steel products are shipped to service centres and distributors, 22% are consumed by the construction sector, 15% by automakers and vehicle manufacturers, 3% are used for the production of packaging, and the rest (around 35%) is used mainly for other industrial applications or traded (Fenton 2005). Not only steel products have commercial applications, for instance slag is used for manufacturing asphaltic aggregates, clinker and concrete, cement additives, railroad ballast or road bases.

The world average consumption of steel products amounted to 178.9 kg per capita in 2009 (see Table 3). The consumption per capita is significantly higher in developed areas (240.7 kg in the European Union) than in developing regions (e.g. 42.1 kg in Africa).

Continuous cast steel output in 2009 was 1149.3 Mt, i.e, almost 94% of crude steel output. The difference between crude steel output and cast steel output accounts for home scrap output. By region, the highest apparent consumption (i.e., the result of adding

TABLE 3

Apparent consumption of finished steel products in 2009

TABELA 3

Wykazane zużycie wyrobów stalowych gotowych w 2009 r.

Region	Finished steel apparent consumption [Mt]	Apparent steel use per capita [kg/person]
European Union	118.4	240.7
Other Europe	23.9	209.8
Former Soviet Union	35.8	140.3
North America	80.9	178.9
Central and South America	33.6	73.9
Africa	26.4	42.1
Middle East	40.7	204.8
Asia	755.4	207.1
Australia and New Zealand	6.1	233.4
World total	1 121.2	178.9

Source: Worldsteel 2010.

production and imports and subtracting exports, without taking into account changes in stock levels) of finished steel products took place in Asia (67.37% of the world total). China's apparent consumption was 48.38% of the total. The European Union and North America were the second and third largest consumers of finished products (10.56% and 7.22% respectively).

2.2. The supply chain of steel

World crude steel production has been increasing steadily since the 70s, from 595 Mt in 1970 to 1414 Mt in 2010 (Worldsteel 2010). Geographically, crude steel production in 2009 was concentrated in Asia (comprising China, India, Japan, South Korea, Taiwan and South East Asian countries: 65.37% of the world total), and China alone accounted for 46.30% of the world total production. Other major producing areas were the European Union (11.33%), the former Soviet Union (8.03%), and North America (US, Canada, and Mexico: 6.65%). Production in developing regions was much smaller.

At the global level most crude steel is produced by primary routes (~72%), while the rest is produced by secondary steelmaking. The open hearth furnace-based production amounted only to 1.3 % (see Table 4). That technology is still used in the former Soviet Union, India, and some South East Asian countries, but it is likely to disappear due to its higher costs with respect to alternative production routes.

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Crude steel production by region and technology in 2009

Produkcja stali surowej w 2009 r., według regionu i technologii

Region	Crude steel production [Mt]	Primary-based production [%]	Secondary-based production [%]	Other[A] [%]
European Union	138.8	55.9	43.6	0.5
Other Europe	28.2	30.6	69.4	0.0
Former Soviet Union	98.3	63.9	21.3	14.8
North America	81.4	37.8	62.2	0.0
Central and South America	38.8	61.0	39.0	0.0
Africa	15.1	33.9	66.1	0.0
Middle East	17.3	11.5	88.5	0.0
Asia	800.7	81.1	18.8	0.1
Australia and New Zealand	6.0	69.6	30.4	0.0
World total	1 224.8	70.6	28.1	1.3

[A] – This column also includes open hearth furnace-based production.
Source: Worldsteel 2010

As regards the intermediate products needed for steelmaking, pig iron production reached 909.60 Mt in 2009, while DRI production was 60.60 Mt. Global iron ore production was 2180.80 Mt in 2008 (see Table 5). Iron ore production is controlled by a few global firms. For instance, in 2003 three firms (Rio Tinto, BHP Billiton, and CVRD) accounted for almost half of the world output of iron ore and 70% of global seaborne iron trade (Nolan 2008).

Since some of the major steel producing countries are not blessed with enough domestic iron sources, there is a significant trade, mostly seaborne (Hidalgo, Calleja, Torrecilla 2007; Yellishetty, Ranjith, Tharumarajah 2010). The cases of Australia and Brazil are typical. Both countries have large deposits of iron ore and metallurgical coal although they are not major steel producers. Iron and coal are rather exported to China and Europe.

Increasing demand from metallurgical industry resulted in a significant increase in global coking coal production, from 480 Mt in 2000 to 793.8 Mt in 2008 (see Table 6), by 65%. Although China was responsible for almost half of the world coking coal production in 2008, its consumption exceeded domestic production. The second biggest coking coal producer is Australia with a yearly output of approximately 142 Mt (Ozga-Blaschke 2010).

Approximately 30% of global coking coal production is traded in the international market. The international trade increased by 40% in 2008 when compared to 2000 reaching almost 260 Mt. Because of remote location of demand regions, 90% of coking coal is shipped by sea. Due to quality requirements, hard-type coking coal is mostly traded internationally

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TABLE 5

Iron ore production, trade, and apparent consumption in 2008

TABELA 5

Produkcja, eksport, import ujawniona konsumpcja rudy żelaza w 2008 r.

Region	Production [Mt]	Exports [Mt]	Imports [Mt]	Apparent consumption [Mt]
European Union	26.5	42.6	181.2	165.2
Other Europe	5.5	1.3	10.2	14.3
Former Soviet Union	188.4	62.6	16.6	142.3
North America	96.6	41.2	22.2	77.6
Central and South America	384.7	299.8	12.1	97.0
Africa	64.1	42.6	7.0	28.5
Middle East	20.0	5.4	18.4	33.1
Asia	1 042.9	110.8	659.6	1 591.6
Australia and New Zealand	352.1	309.4	4.6	47.3
World total	2 180.8	915.6	931.9	2 197.7

Source: Worldsteel 2010.

TABLE 6

Coking coal production and apparent consumption in 2008

TABELA 6

Produkcja i ujawniona konsumpcja węgla koksowego w 2008 r.

Region	Production [Mt]	Apparent consumption [Mt]
Former Soviet Union	88.3	83.6
Europe	31.2	86.3
Central and South America	0.8	13.0
North America	87.6	26.0
Africa	3.5	5.5
Australia and New Zealand	142.5	4.5
China	385.0	387.5
Other Asia	54.9	135.4
World total	793.8	741.8

Source: Ozga-Blaschke 2010.

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(approx. 130–140 Mt) and the market, as in the case of iron ore, is dominated by five key producers-exporters: BHP Billiton Mitsubishi Alliance (33%), Teck Cominco (16%), Anglo American/Mitsui (8%), Xstrata (7%) and Rio Tinto (6%) (Ozga-Blaschke 2010).

The most important importers of coking coal are located in Asia. Japan, being the biggest, imported 57.4 Mt in 2008, Korea 24.1 Mt and India 28.8 Mt (see Table 8). China gradually increased coking coal imports to cover domestic demand. As concerns Europe, coking coal is imported mainly to Germany, Italy, France and the UK.

Trade figures are also remarkable for scrap, because of its sheer volume with respect to the steel production levels and the long distances involved in that trade. In 2008 world scrap exports reached 89.5 Mt, while imports were 107.7 Mt (see Table 9). The European Union

TABLE 7

Main exporters of coking coal in 2000/2008

TABELA 7

Główni eksporterzy węgla koksowego w 2000 i 2008 r.

Exporting country	2000 [Mt]	2008 [Mt]
China	6.5	0.7
Russia	7.3	12.2
Canada	28.4	21.2
USA	29.8	33.8
Australia	99.8	133.5

Source: Ozga-Blaschke 2010.

TABLE 8

Main importers of coking coal in 2000/2008

TABELA 8

Główni importerzy węgla koksowego w 2000 i 2008 r.

Importing country	2000 [Mt]	2008 [Mt]
Italy	7.2	7.5
France	6.5	7.3
UK	8.5	6.3
Germany	4.6	9.3
China	0.3	6.9
India	11.1	28.8
Korea	19.6	24.1
Japan	57.1	57.4

Source: Ozga-Blaschke 2010.

TABLE 9

Steel and scrap trade in 2008

TABELA 9

Handel stalą i złomem w 2008 r.

Region	Steel exports [Mt]	Steel imports [Mt]	Scrap exports [Mt]	Scrap imports [Mt]
European Union	155.6	162.2	42.7	39.5
Other Europe	23.1	22.4	2.2	18.9
Former Soviet Union	62.7	15.6	0.8	0.9
North America	26.0	46.8	26.8	15.0
Central and South America	13.6	13.9	0.7	0.4
Africa	0.0	20.3	4.6	2.7
eepnMiddle East	9.5	40.2	0.3	0.0
Asia	140.4	107.9	7.9	29.1
Australia and New Zealand	1.8	87.8	2.0	0.0
World total	432.7	432.7	89.5	107.7

Souce: Worldsteel 2010.

and Asia are the major importers of scrap. The European Union was also the major supplier, followed by the US. Steel scrap is an outstanding example of recycling via market, especially in the US. The scrap processing industry is global, and prices are determined by demand and supply in world markets. The supply of new scrap is a function of industrial activity, and thus whenever the activity is high more industrial scrap is generated. Scrap prices affect the prices of iron ore, pig iron, and DRI. World prices are set in the US, which is the largest open scrap market. There is no futures market for scrap. Scrap prices experience seasonal changes, tending to rise significantly in winter, while falling in spring and summer. Prices are influenced by the demand for steel, and also by transport costs (especially shipping). The scrap industry uses inventories to absorb price differentials. The scrap industry consists of collectors and small dealers, large dealers and processors, and brokers. Collectors and small dealers generally handle all types of recyclable scrap, and the large dealers and processors specialize in iron and steel scrap, nonferrous metals, waste paper, and so forth (Fenton 2005). There is no clear pattern of consolidation or globalization in the global scrap industry. A few large firms are able to operate globally, but there are many small firms in almost every country. Even the leading suppliers are price takers, and the industry seems to be rather competitive (Aylen, Albertson 2006).

Steel products are also traded significantly, and exports have almost trebled since the 70s. In 1975, 22.6% of the global steel production (that is, 114.7 Mt) was exported. In 2008 exports amounted to 436.2 Mt, 34.9% of the world production. There are significant trade

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imbalances in some regions, especially in the former Soviet Union, North America, Africa, the Middle East, and Australia and New Zealand. At the country level, the highest imbalances are found in China (15.6 Mt of imports versus 56.3 Mt of exports) and Japan (4.5 Mt of imports, 36.9 Mt of exports).

2.3. Prices and costs

Steel prices depend on several variables, and there is not a single price for steel since there is a great variety of steel products. The technology choice for steelmaking is a key determinant of the price. Table 10 shows the ranges of different costs categories by technology.

TABLE 10

Estimated cost ranges in 2010 (USD2000)

TABELA 10

Oszacowanie zakresu kosztów produkcji stali 2010 r. (USD2000)

Production route	Investment costs [USD/t of hot metal]	Fixed O&M costs [USD/t of hot metal]	Variable O&M costs[A] [USD/t of hot metal]
BF-OHF	–	–	–
BF-BOF	148–275	10–15	90
SR-BOF	98–320	10–15	13–19
DR-EAF	142	–	–
EAF	80	–	–

[A] – input costs not included.
Source: ETSAP 2010.

The previous table does not consider the prices of inputs. Those prices depend on supply and demand interaction (between steelmakers and consumers, but also on interaction with other industries competing for the same inputs), and on transport conditions. Table 11 shows a selection of prices of different inputs, as well as some prices of finished products.

The raw material and energy costs of steel production are strongly interrelated, and closely linked with other technological variables and firm's know-how. For instance, availability of iron ores of appropriate quality has a significant impact on energy and material efficiencies. Iron ores used in China were in general of inferior grade (with an average iron content of 34%) and the steel produced in China had high coke rates and high iron-to-steel efficiency. On the other hand, in the 70s and 80s, Japanese steelmakers signed long-term contracts ensuring supplies of high-quality ores from Brazil and Australia. Afterwards, the price of ore decreased to the point where Japanese firms could secure ores at prices well below the cost incurred by other companies, even taking into account the shipping costs.

This led to increments in market shares and profits of the Japanese companies, which also led to further investments and technological improvements. Technology improvements are also triggered by increasing energy prices, in an effort to improve energy efficiency and reduce

TABLE 11

Prices of selected energy inputs, raw materials, and finished steel products

TABELA 11

Ceny wybranych nośników energii, surowców mineralnych i produktów stalowych gotowych

	Commodity	Unit	2000	2005	2010
Energy inputs	coal (Australia)[A]	USD 2000/t	26.25	43.24	82.06
	natural gas (US)[B]	USD 2000/GJ	4.09	7.68	3.45
	natural gas (EU)[C]	USD 2000/GJ	3.66	5.44	6.51
	natural gas (Japan)[D]	USD 2000/GJ	4.46	5.16	8.53
Materials	iron ore (fob)[E]	$1/100 \cdot$ USD 2000/dmtu[N]	28.79	59.02	n.a.
	iron ore (cfr spot)[F]	USD 2000/dmtu[N]	n.a.	n.a.	120.95
	iron ore (US)[G]	USD 1998	24.40	36.60	n.a.
	scrap (US)[H]	USD 1998	90.00	n.a.	n.a.
	lime (US)[I]	USD 1998	59.40	79.80	n.a.
Finished steel products	cold-rolled coil/sheet[J]	USD 2000/t	385.83	665.84	676.33
	hot-rolled coil/sheet[K]	USD 2000/t	295.83	575.05	593.41
	rebar[L]	USD 2000/t	244.17	384.18	466.44
	wire rod[M]	USD 2000/t	291.67	525.86	590.58

[A] – Thermal coal, fob, shipped from Newcastle-Port Kembla (World Bank Commodity Markets).

[B] – Spot price at Henry Hub, Lousiana (World Bank Commodity Markets).

[C] – Average import border price (World Bank Commodity Markets).

[D] – LNG import price, cif (World Bank Commodity Markets).

[E] – Brazilian iron ore, dmtu: dry metric ton of 1% Fe (World Bank Commodity Markets)

[F] – Iron ore (any origin) fines, spot price, cfr China, 62% Fe (World Bank Commodity Markets).

[G] – Average composite price per metric ton of steel apparent consumption (USGS).

[H] – US No. 1 Heavy Melting Scrap

[I] – Average composite price per metric ton of steel apparent consumption (USGS).

[J] – Cold-rolled coil/sheet (Japan) producers' export contracts fob mainly to Asia (World Bank Commodity Markets).

[K] – Hot-rolled coil/sheet (Japan) producers' export contracts (3 to 12 months terms) fob mainly to Asia

[L] – Rebar (Japan) producers' export contracts fob mainly to Asia (World Bank Commodity Markets).

[M] – Wire rod (Japan) producers' export contracts fob mainly to Asia (World Bank Commodity Markets).

[N] – Dry Metric Ton Unit (dmtu) is the internationally agreed-upon unit of measure for iron ore pricing. It has the same mass value as a metric ton, but the material has been dried to decrease the moisture level. A dry metric ton unit consists of 1% of iron (Fe) contained in a ton of ore, excluding moisture. The price per ton of a certain quantity of iron ore is calculated by multiplying the cents/dmtu price by the percentage of iron content. Iron ore contracts are quoted in US Cents.

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releases, although the impact of this driving factor tends to be overestimated. Energy prices do not cause a significant change in the diffusion of integrated factories or mini-mills, since that is also highly influenced by other factors such as the availability of scrap. Other determinants are related with prices and quality of reducing agents. For instance, in the US iron and steel industry, higher coke prices are perceived as the main driver behind the introduction of BOF and the early deployment of EAF.

Further impact on the process of technology selection and energy efficiency is potentially foreseen to come from investments in more diversified and reliable energy system, demand side management, and technology-related investments. As an example, improvements in natural gas infrastructure and technology, power recovery, and direct coal injection significantly increased energy efficiency of the Chinese steel sector. Also improvements in mini-mills' electricity consumption shows energy-related advantages of mini-mills.

2.4. Consolidation of the steelmaking firms

World-wide consolidation of steelmaking firms has been taking place since the 70s in order to improve economies of scale, and also in order to reduce overcapacity (Fenton 2005). During the 30s and 40s steelmaking was regarded as a strategic industry and was state--protected. Many countries had a state-owned company dominating the domestic market. Until the 70s the steel industry obtained sustained profits that led to a stable growth. The economic recession of the 70s resulted in overcapacity and pessimistic forecasts of future demand for steel products. As a consequence, state-owned steelmakers began to be privatized; while most producers reorganized their operations in an attempt to achieve higher profitability. This process was led mostly by European and Japanese companies, and US steelmakers lagged behind. Companies made up of integrated mills and producing small outputs, or facing competition with the cheaper mini-mills, began to be shut down or sold to other firms. From 1995 to 2005 the world steel industry entered a period of intense merger and acquisition. In 1995 the top ten producers supplied ~20% of the global steel output. The surviving companies after this consolidation process were far bigger than those existing at the beginning and by 2005 their total share in world steel output reached ~29%.

With the consolidation of the industry technological changes needed larger investments, as efficiency improvements (not related with increased economies of scale) slowed down. That, and the lack of profits and access to capital, reduced the rate of technological change. The situation was worsened by failures to anticipate changes consumer needs and cost saving potentials of new technologies (Ayres et al. 2004).

Table 12 illustrates the recent consolidation process experienced by the steelmaking industry. In 2001 Arcelor (resulting from the merger of the three largest European steelmakers: the French Usinor, the Luxembourg-based Arbed, and the Spanish Aceralia) overtook Nippon Steel and became the world largest producer. The Mittal Steel Company: company began operations in 1976 under the name Ispat. Since then it followed a strategy based on the acquisition of under-performing steel mills around the world. In 1998 it

Steel firm's rank and output (1995–2004)

Ranking i wielkość produkcji największych producentów stali (1995–2004)

Rank	1995		1998		2002		2004	
	Firm	Output [Mt]	Firm	Output [Mt]	Firm	Output [Mt]	Firm	Output [Mt]
1	Nippon	27.8	Posco	25.6	Arcelor	44.0	Mittal	57.0
2	Posco	23.4	Nippon	25.1	LNM Group	34.8	Arcelor	43.0
3	British Steel	15.7	Arbed	20.1	Nippon	29.8	Posco	32.0
4	Usinor	15.5	Usinor	18.9	JFE	28.9	Nippon	32.0
5	Riva Group	14.4	LNM Group	17.1	Posco	28.1	JFE	30.0
6	US Steel	12.1	British Steel	16.3	Baosteel	19.5	Nucor	20.0
7	NKK	12.0	Thyssen Krupp	14.8	Corus	16.8	US Steel	20.0
8	Arbed	11.5	Riva Group	13.3	Thyssen Krupp	16.4	Thyssen Krupp	20.0
9	Kawasaki	11.1	NKK	11.5	US Steel	14.4	Baosteel	20.0
10	Sumitomo	10.7	USX	11.0	Nucor	12.4	Corus	19.0

Source: Nolan 2008.

acquired the 6th largest steelmaker in the US. After 2000 it acquired several companies in Central and Eastern Europe. In 2004 it acquired the US-based International Steel Company, and the resulting firm was renamed the Mittal Steel Company. By 2007 it merged with Arcelor becoming ArcelorMittal. But those were not the only mergers. JFE resulted from the merger in 2003 of the Japanese NKK and Kawasaki. The US-based Nucor resulted from the merger of BHP (Australia), Trico (US), and Birmingham (US) in 2002–2003. US Steel acquired National Steel (also US-based) in 2003. In China, Baosteel was formed in 1998 from the absorption of Shanghai Metallurgy Holdings and the Meishan Group by the Baoshan Iron and Steel Corporation. In the EU Thyssen and Krupp became Thyssen-Krupp in 1999, the same year British Steel (UK) merged with Hoogovens (NL) forming Corus, which was acquired by India's Tata Steel in 2007 (Nolan 2008).

As a measure of production concentration, the Herfindahl-Hirschman Index (HHI) was applied in this study, defined as the sum of the squares of the market shares of N producers. If the value is below 0.01 the market is supposed to be highly competitive. Below 0.15, the market would not be concentrated. Values between 0.15 and 0.25 indicate moderate concentration. Higher values would imply high concentration, suitable for exerting market power (Rhoades 1993).

In 2009, almost 50% of the world production (1227 Mt) was provided by the 49 firms listed in Table 13, which provides production levels and country of domicile. A calculation of

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Top producers (only members of WorldSteel; with crude steel production over 3 Mt) in 2009

Ranking producentów stali (członkowie WorldSteel, wielkość produkcji powyżej 3 Mt) w 2009 r.

Rank	Company	Production [Mt]	HQ country	Rank	Company	Production [Mt]	HQ country
1	Arcelor Mittal	77.5	Luxembourg	26	Hyundai	8.4	South Korea
2	Baosteel	31.3	China	27	CEL SA	7.8	Spain
3	POSCO	31.1	South Korea	28	Metinvest	7.4	Russia
4	Nippon Steel	26.5	Japan	29	Techint	6.9	Italy
5	JFE	25.8	Japan	30	Erdemir	6.5	Turkey
6	Jingsu Shagang	20.5	China	31	Metalloinvest	6.5	Russia
7	Tata Steel	20.5	India	32	Kobe	5.9	Japan
8	Ansteel	20.1	China	33	Usiminas	5.6	Brazil
9	Severstal	16.7	Russia	34	JSW	5.5	India
10	Evraz	15.3	Russia	35	Essar	5.5	India
11	U.S. Steel	15.2	US	36	Voestalpine	5.5	Austria
12	Shougang	15.1	China	37	Salzgitter	4.9	Germany
13	Gerdau	14.2	Brazil	38	Hadeed	4.8	Saudi Arabia
14	Nucor	14.0	US	39	BlueScope	4.6	Australia
15	Wuhan	13.7	China	40	CSN	4.4	Brazil
16	SAIL	13.5	India	41	Ezz	3.9	Egypt
17	Handan	12.0	China	42	SSAB	3.6	Sweden
18	Riva	11.3	Italy	43	Sidor	3.1	Venezuela
19	Sumitomo	11.0	Japan	44	Duferco	3.1	Belgium
20	ThyssenKrupp	11.0	Germany	45	Nisshin	3.1	Japan
21	Novolipetsk	10.9	Russia	46	Vizag	3.1	India
22	IMIDRO	10.6	Iran	47	CMC	3.1	US
23	Magnitogorsk	9.6	Russia	48	AHMSA	3.1	Mexico
24	China Steel	8.9	Taiwan	49	Dongkuk	3.1	Korea
25	Laiwu	8.9	China		Others[A]	<3.1	

[A] – This includes the rest of the production up to 1227 Mt, that is 643 Mt. Assuming that the production of each of those producers is lower than 3 Mt per year, there would be at least 215 steel makers more.

the country-based HHI using the country shares in global crude steel production (not provided in the document) yields a value of 0.23, which shows that the steel industry is moderately concentrated, but very close to a high concentration level. If the index takes into account production by the steelmaking firms listed in Table 13, the HHI obtained is 0.01, which indicates a non-concentrated market. These disagreeing results prove the need for further research in order to provide useful insights into the developments of such an important economic sector, and especially into the consequences of the recent world-wide consolidation trends observed in the last years.

3. Concluding remarks

The iron and steel industry is a very complex sector which is intrinsically linked with the rest of the world economy. Steelmaking is highly material and energy-intensive, which combined with the unequal geographical distribution of resources needed for manufacturing steel products and meeting final demand gives rise to significant trade flows. All those factors have a particular impact on supply and demand patterns, and on prices.

There are two basic production methods that account for most of the production: (i) primary steelmaking (~72% of the global production) and (ii) secondary steelmaking (~28% of the global production). The first route requires the consumption of iron ore, coal, limestone, and scrap, plus the use of large facilities, while the second may rely on the use of scrap and electricity in smaller factories. Most steelmaking routes are energy-intensive and highly dependent on the use of solid fossil fuels. In 2006 world final energy consumption in the iron and steel industries amounted to 4.76% of global final energy consumption. Steelmaking is also a major source of greenhouse gas (GHG) emissions and air pollution. Global direct CO_2 emissions from final energy consumption in the iron and steel industry amounted to in 2006 to 3.70% of total CO_2 emissions from fuel combustion. Thus, steelmaking is one of the industrial sectors most affected by the current efforts to fight global climate change (such as the European emission trading scheme).

Steel consumption is commonly linked to GDP per capita levels through the so-called steel intensity, which can be described as a function that, although depends on the country considered, usually follows an inverse U-shaped curve. Continuously cast steel output in 2009 was 1149.3 Mt. Most of the consumption was absorbed by Asia (China), the European Union and the US. World crude steel production has been increasing steadily since the 70s, from 595 Mt in 1970 to 1414 Mt in 2010.

In order to meet the demand of finished products, steelmakers need a steady supply of raw materials (mainly iron ore, coking coal and scrap), whose production is usually controlled by a few key producers (except in the case of scrap), and requires significant trade flows. Steel products are also traded significantly, and exports have almost trebled since the 70s. As in the case of raw materials, there are remarkable trade imbalances in some regions.

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Steel prices depend on several variables, and there is not a single price for steel since there is a multitude of steel products. Those prices depend on supply and demand interaction (between steelmakers and consumers, but also on interaction with other industries competing for the same inputs), and on transport conditions. The raw material and energy costs of steel production are strongly interrelated, and closely linked with other technological variables and firm's know-how.

World-wide consolidation of steelmaking firms has been taking place since the 70s in order to improve economies of scale, and also in order to reduce overcapacity. The current steel industry is made up of some large firms that operate globally and produce a significant output, and many small firms that operate at a smaller scale. The industry has been the subject of oligopolistic analyses since the 50s to date (not to mention the countless engineering--related studies). However, despite the historical consolidation trends towards multinational companies, rather than being world-wide those analyses focus on specific countries and regions. On the other hand most analyses also expect that the industry will reach higher levels of consolidation in the forthcoming years. Therefore, any future mid or long term analysis of the steel industry should take into account that trend and the global nature of the sector. Moreover, given the complexity of all the relationships outlined previously, exclusive reliance on expert analysis does not seem to guarantee the gaining of a proper and comprehensive insight into the prospects of this key economic sector. The main conclusion of this overview is that any future analysis of the iron and steel industry should be based on quantitative modelling tools that: (i) properly capture the technological diversity of the industry and the key features of the supply chain, (ii) are able to consider the strategic behaviour of all the key players of the industry, and (iii) consider all those factors at the global scale.

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PRZEMYSŁ ŻELAZA I STALI: ANALIZA STANU OBECNEGO Z PERSPEKTYWY RYNKU ŚWIATOWEGO

S ł o w a   k l u c z o w e

Przemysł żelaza i stali, rynek międzynarodowy, surowce mineralne, konsolidacja, siła rynkowa

S t r e s z c z e n i e

W artykule przedstawiono stan obecny rozwoju technologii wykorzystywanych w hutnictwie żelaza i stali z punktu widzenia rynku światowego. Sektor produkcji żelaza i stali charakteryzuje się bardzo skomplikowanymi zależnościami, ze względu na silne powiązanie z resztą gospodarki oraz znaczenie wyrobów stalowych dla innych sektorów przemysłowych, takich jak na przykład budownictwo, motoryzacja itp. Ponadto, hutnictwo żelaza i stali wymaga znacznych ilości surowców mineralnych i energii, a większość firm produkujących surowce mineralne jest zlokalizowanych z dala od obszarów o najwyższym popycie na stal. W konsekwencji, zarówno wyroby stalowe jak i surowce mineralne są przedmiotem handlu międzynarodowego (głównie drogą morską), co dodatkowo utrudnia prowadzenie analiz dotyczących sektora hutnictwa żelaza i stali. Ceny stali, a w zasadzie poszczególnych wyrobów stalowych, które są przedmiotem obrotu, zależą od wielu czynników. Do najważniejszych z nich należą przede wszystkim zgłaszany przez konsumentów popyt, zdolności produkcyjne oraz aktualna sytuacja w międzynarodowym transporcie.

Jeśli chodzi o strukturę własności, w przemyśle stalowym funkcjonuje kilka dużych firm, które mają swoje huty w całym świecie (często zakupione w procesie prywatyzacji lub w wyniku fuzji z innymi przedsiębiorstwami) oraz wiele małych firm, które działają na znacznie mniejszą skalę. W ostatnim czasie niektóre firmy przeszły proces konsolidacji i fuzji w wyniku czego powstały koncerny międzynarodowe (takie jak ArcelorMittal, który powstał w 2006 roku w wyniku fuzji Arcelora i Mittal Steel; Arcelor powstał z kolei w wyniku połączenia Aceralia (Hiszpania), Usinor (Francja) i Arbed (Luksemburg) w 2002 r.).

Wyniki analizy zaprezentowanej w niniejszym artykule stanowią podstawę do dalszych badań w zakresie długo- i średniookresowych perspektyw rozwoju światowego przemysłu stalowego. Analizy w zakresie rozwoju przemysłu żelaza i stali powinny być oparte na narzędziach ilościowych (modele matematyczne) które umożliwiają: (i) właściwe uchwycenie różnorodności technologicznej przemysłu i głównych cech łańcucha dostaw surowców mineralnych i energii, (ii) odzwierciedlenie różnych strategii przyjmowanych przez poszczególnych kluczowych graczy w branży oraz (iii) wzięcie pod uwagę wszystkich wspomnianych czynników na poziomie rynku międzynarodowego.

THE IRON AND STEEL INDUSTRY: A GLOBAL MARKET PERSPECTIVE

Abstract

The paper presents a global perspective of the current technologies used for steel production and the steel markets. The iron and steel industry is a very complex sector that is strongly related with the rest of the economy due to the importance of steel products for industries such as construction, automotive, and other manufacturing sectors. Moreover, the iron and steel industry demands significant amounts of raw materials and energy, and most companies producing raw materials are located remote from the areas of highest steel demand. In consequence, both steel products and inputs are traded internationally (mostly by sea) and in large quantities, what additionally complicates analyses of the iron and steel industry. Steel prices depend on several variables, and there is not a single price for steel since there is a great variety of steel products traded. Those prices depend on supply and demand interaction (between steel producers and consumers, but also on interaction with other industries competing for the same inputs), and on transport conditions.

As concerns the ownership structure, the steel industry consists of some large firms that operate globally and produce significant output, and many small firms that operate at a lesser scale. Recently, some of those firms have consolidated into large multinationals (such as ArcelorMittal, formed in 2006 by the merger of Arcelor and Mittal Steel, Arcelor being the result of the previous merger of Aceralia (ES), Usinor (FR), and Arbed (LX) in 2002).

The results of this article form the basis for further long- and mid-term analyses of the development of the global steel industry. The main conclusion of the paper is that any future analysis of the iron and steel industry should be based on quantitative modelling tools that: (i) properly capture the technological diversity of the industry and the key features of the supply chain, (ii) are able to consider the strategic behaviour of all the key players of the industry, and (iii) consider all those factors at the global scale.