International Energy Efficiency Comparisons and Policy Implications in the Iron and Steel Industry

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Synopsis.

International comparisons of energy efficiency in the steel industry are used to analyse differences in efficiency and make recommendations for energy efficiency policy.

Abstract.

Energy consumption of the iron and steel industry during the period 1980-1991 was studied in seven countries (Brazil, China, France, Germany, Japan, Poland and the USA). To understand trends in Poland, we compare developments there with those of the countries over time. Using a decomposition analysis based on physical indicators we decompose the changes in intra-sectoral structural changes and efficiency improvements. Energy intensity decreased in all countries, except Poland. Efficiency improvement played a major role in Brazil, China, Germany and the USA, while structural changes seem to be the major driver for energy savings in France and Japan. The methodology also makes it possible to estimate the potential for energy efficiency improvement relative to a 'best-practice' reference plant. In Poland the potentials (in 1991) was 43%, compared to a low of 9% for Germany, and a high of 63% for China. Finally, based on an understanding of past energy efficiency developments we discuss opportunities and measures for the iron and steel industry.

1. Introduction

Establishing effective energy efficiency policies requires detailed knowledge regarding past trends, opportunities and potentials for improvement, and the effectiveness of policies and measures designed to increase energy efficiency. In this paper, we compare the iron and steelmaking in Poland to that in Brazil, China, France, Germany[1], Japan, and the United States (U.S.). About half of the world's steel production occurs in these seven countries (IISI 1992). Data on production levels, processes, and energy use are generally available for the iron and steel sector, making it possible to analyse national trends and make international comparisons of the energy intensity of steelmaking on a physical basis (e.g. per tonne of product).

In the past many analyses have used economic indicators to express energy intensity (e.g. energy use per $ value added) to track energy use and efficiency trends. However, because changes in product mix or process mix are generally not captured in many economic decomposition analyses, it is difficult to analyse changes in the production structure of an industry using economic indicators. It is unclear whether such economic indicators are appropriate proxies for physical energy use. A comparison of economic indicators to the specific energy consumption (SEC) in these countries found that the economic indicators did not track developments well in Poland, Brazil or China, and large differences occurred between years in the case of OECD countries (Worrell *et al.* 1997). Therefore, we use physical intensity indicators to perform a decomposition analysis to distinguish changes in activity, structure, and energy intensity in iron and steelmaking. Using physical indicators improves comparability between countries, provides greater information for policy-makers regarding intra-sectoral structural changes, and provides detailed explanations for observed changes in energy intensity. The decomposition analysis helps to understand energy efficiency trends and to formulate energy efficiency improvement policies. By comparison to developments in other countries we discuss opportunities and policy measures to increase the energy efficiency in the iron and steel industry in Poland.

Currently there are two main routes for the production of steel: production of primary steel using iron ore and scrap and production of secondary steel using scrap only. A wide variety of steel products are produced by the industry, ranging from slabs and ingots to thin sheets, which are used in turn by a large number of other manufacturing industries. Crude steel production volumes and shares of the different production processes in 1990 for the countries analysed in this paper are given in Table 1-1.

Table 1-1. Crude steel production volumes and shares of the main iron and steel production processes in selected countries in 1990 (IISI 1992). The production share of steelmaking processes are given, where BOF is the basic oxygen furnace, OHF open hearth furnace and EAF electric are furnace. The share of continuous casting (CCM) is an important indicator for the state-of-the-art of the industry.

Process	Pig iron Mtonnes	Crude steel Mtonnes	Share	Share BOF %	Share OHF %	Share EAFCCM % %
Brazil	21.14	20.57	74%	4%[1]	24%	58%
China	62.37	66.26	59%	20%	21%	22%
France	14.42	19.02	72%	0%	28%	94%
Germany [2]	30.10	38.42	82%	0%	19%	91%
Japan	80.23	110.34	69%	0%	31%	94%
Poland	8.42	13.63	53%	29%	18%	8%
USA	49.67	89.72	59%	4%	37%	67%

Notes: 1. The Brazilian industry applies 4% other steelmaking processes (no OHF); 2. Germany includes only the old-Bundesländer of the FRG.

First, we describe the methodologies used for our comparisons. The results of our analysis are presented along with a discussion of country-specific trends, followed by policy recommendations to improve the energy efficiency of the Polish iron and steel industry. We end with conclusions on the applicability of the methodology and recommendations.

2. Methodology

We examine three basic elements of energy use in iron and steelmaking: activity, structure, and energy intensity. Activity is defined as production of crude steel. Structural factors include the feedstock type, i.e. iron ore and scrap, and product mix (slabs, hot rolled steel, cold rolled steel). Energy intensity, or specific energy consumption (SEC), (e.g. GJ/tonne), is a result of the efficiency of the iron and steelmaking processes.

Energy is measured as the consumption of primary energy carriers. Fuel inputs (coal, oil products, gas) are calculated on the basis of lower heating values, as is common in International Energy Agency (IEA) and United Nations Statistics (IEA 1993). Cokemaking has not been taken into account in the analysis as coke production is a separate sector in many statistics. Energy consumption of cokemaking may vary, as well as the coke input rates in the blast furnaces (IISI 1996b). We have used national statistics for the energy and production data (Worrell et al. 1997).

Primary values for electricity generation were calculated by multiplying electricity consumption by the world average efficiency (33% in 1990) (Faaij et al. 1995), in order to highlight the changes and differences in energy intensities in the iron and steel industry, rather than those in the electricity sector of a country. Using such a standard conversion efficiency makes the comparisons of trends in the iron and steel sector more transparent, but can obscure changes in electricity generation efficiencies over time and differences between countries. This can be problematic for countries like Brazil that produce electricity predominantly from hydroelectric sources. The effects of cogeneration (combined heat and power) are also obscured with a standard electricity conversion. For further discussion of the effects of varying electricity generation efficiencies, see Worrell et al. (1997).

2.1 Physical intensity indicator: specific energy consumption

Specific energy consumption (SEC) is defined as the amount of energy (in enthalpy) needed to produce a tonne of a certain steel product. The SEC is influenced by three main factors: feedstock (determining production process), the type of products produced, and the efficiency of the production process. The primary energy carrier used can also affect the energy efficiency. We do not consider the variety of fuels available, but treat fuels as one single energy carrier, since most iron and steel industries in the selected countries are assumed to have access to most types of energy carriers, and coal and coke are the dominant fuels in this sector. Electricity is counted as primary energy (see above), using the same efficiency cross-country and cross-time.

The most important input-factor influencing energy consumption in the iron and steel industry is the feedstock: iron ore and scrap for primary steel or scrap only for secondary steel. We do not include direct reduction in this study because of its small contribution to iron production in the investigated countries (IISI 1992). The production of primary steel consumes more energy but produces a higher quality steel. In the Basic Oxygen Furnace (BOF) the amount of scrap used is different for each plant. Scrap use (instead of pig iron) is both a technical and an economic issue. The quality of the steel might be influenced by impurities in the scrap. Scrap prices have increased due to the increasing share of Electric Arc Furnace (EAF) production in steelmaking worldwide, making pig iron relatively less expensive.

The main output-factor influencing energy consumption is the product type. We have aggregated the various product types into three categories that represent the most important product categories from the perspective of energy consumption: ingots and slabs, hot rolled steel (including plates, strip, wire, and long steel products) and cold rolled products (cold rolled sheet and strip). Production is defined as the total output of usable ingots, continuously cast semi-finished products, and liquid steel for castings. Steel production is allocated to categories on the basis of deliveries (IISI 1992). Finishing (e.g. galvanizing, annealing) has not been accounted for in the analysis. This introduces an uncertainty in the calculations, dependent on the share of finished product. For the selected countries the uncertainty in the SEC due to finishing is less than 1% (Worrell et al. 1997).

2.2 Decomposition analysis methodology

We have followed the simple average parametric Divisia decomposition methodology proposed by Farla et al. (1997) to understand the factors that contribute to the SEC. The aggregated SEC is calculated by dividing total primary energy consumption in the iron and steel industry by total production. Because product types change over time and differ by country, a weighting factor is used to calculate a physical production index (PPI) instead of simply summing all steel products. The weight factors are based on the energy used to produce each steel product using existing best practice. We assign weight factors for production of slabs and ingots by both the BOF and EAF processes, for production of hot rolled steel, and for production of cold rolled steel. The weighting factors are provided in Table 2.1.

Table 2-1. "Best Practice" weighting factors for various steel products used in the physical decomposition analysis.

Product (GJ/tonne)	Fuel (GJ/tonne)	Electricity (GJ/tonne) 5	Primary energy
BF-BOF-Slab[1]	14.24	0.36	15.3
EAF-Slab[2]	0.79	1.52	5.4
Hot Rolling[3]	1.82	0.37	2.9
Cold Rolling[4]	1.10	0.53	2.7

Notes: 1. Equivalent to the 1988 SEC of an integrated steel plant in The Netherlands, assuming 10% scrap addition in the BOF (Worrell et al. 1993); 2. Equivalent to the SEC of an EAF plant in Germany (Teoh 1989) and the SEC for continuous casting equivalent to the integrated steel plant (Worrell et al. 1993); 3. Equivalent to the 1988 SEC of a hot strip mill at an integrated steel plant in The Netherlands (Worrell et al. 1993). The SEC of wire rod production is comparable to the given SEC (IISI 1982); 4. Equivalent to the 1988 SEC of a cold rolling mill at an integrated steel plant (Worrell et al. 1993); 5. Calculated SEC assuming an electricity generation efficiency of 33%.

The total energy consumption of the sector is a function of the volume of the output (activity), the process and product mix (structure), and the energy efficiency of the production processes. Using the index decomposition, the influences of changes in activity, structure or product mix, and efficiency on the energy consumption can be calculated.

2.3 Structure/efficiency analysis methodology

In addition to the decomposition analysis, we examine changes in the SEC over time using a structure/efficiency analysis methodology. The SEC is a function of changes in product mix (production structure) and energy efficiency (Phylipsen et al. 1997). If more than one factor influences the production structure it is difficult to illustrate the relationship. We use a structure/efficiency analysis to show the SEC as a function of an important structural factor, i.e. share of secondary (EAF) steelmaking in the product mix (Worrell et al. 1994). We plot both the actual SEC and a "best practice" SEC (SEC_{BP}) which is calculated on the basis of the product and process mix (PPI) and the SEC_{BP} for each of the products, as presented in Table 2.1.[2] The difference between the actual SEC and estimated SEC_{BP} for a given year presents an estimate of the energy efficiency improvement potential (relative to the chosen "best practice" technologies in a specific year), and hence measurement of the energy efficiency (Worrell et al. 1994). The structure/efficiency analysis helps to explain the observed changes in energy use in a sector and countries, as a function of intra-sectoral structural changes and inter-country differences.

3. Results

In this section we discuss the results of the analysis, focusing first on specific energy consumption trends and then on the results of the physical decomposition analysis and the structure/efficiency analysis.

Steel production varied in the selected countries over the study period, remaining nearly constant in Germany and Japan, increasing in China (on average 6%/yr) and Brazil (4%/yr), and decreasing in France (-2%/yr), Poland (-5%/yr), and the U.S. (-2%/yr). The decrease in Poland was due to the economic restructuring process that began in the last years of the analysed period.

3.1 Specific energy consumption trends

The SEC for iron and steel production in the seven countries is calculated by dividing primary energy consumption in the iron and steel industry by total crude steel production. The SECs are plotted in Figure 3-1 and show a general trend towards a reduction in SECs in most countries over the study period. Iron and steel production is least energy-intensive in Germany and Japan and most energy-intensive in China. In comparing the efficiency of the Chinese steel industry to the other countries it should be noted that the use of cast iron is relatively high in China and that energy is also used for so-called “non-productive use” such as residential energy use by employees. Correcting for these factors may lead to 5-6% lower energy consumption in the Chinese iron and steel industry (Ross and Feng 1991).

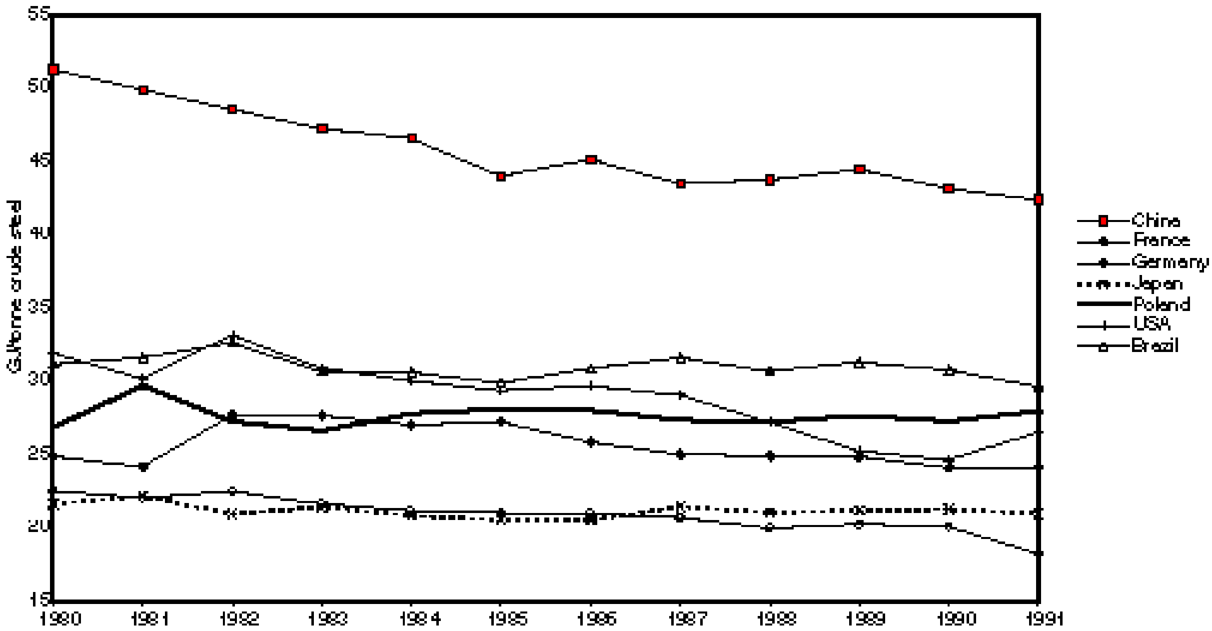

Figure 3-1. Specific energy consumption for iron and steel production in seven selected countries, 1980-1991.

3.2 Decomposition analysis

Figure 3-2 and Table 3-1 present the relative changes in the primary energy consumption between 1980 and 1991. The third bar for each country represents the aggregate change in SEC between 1980 and 1991. The first and second bars represent the contribution of structural changes and efficiency improvement, respectively, to the overall change in SEC during the period. The sum of the efficiency and structural changes equals the change in the overall SEC for the period. Table 3-1 presents the changes in actual values (GJ/tonne), as well as relative percentage changes. Of the countries which experienced the largest decline in intensity (China, Germany, U.S.), energy efficiency improvements accounted for the majority of the change.

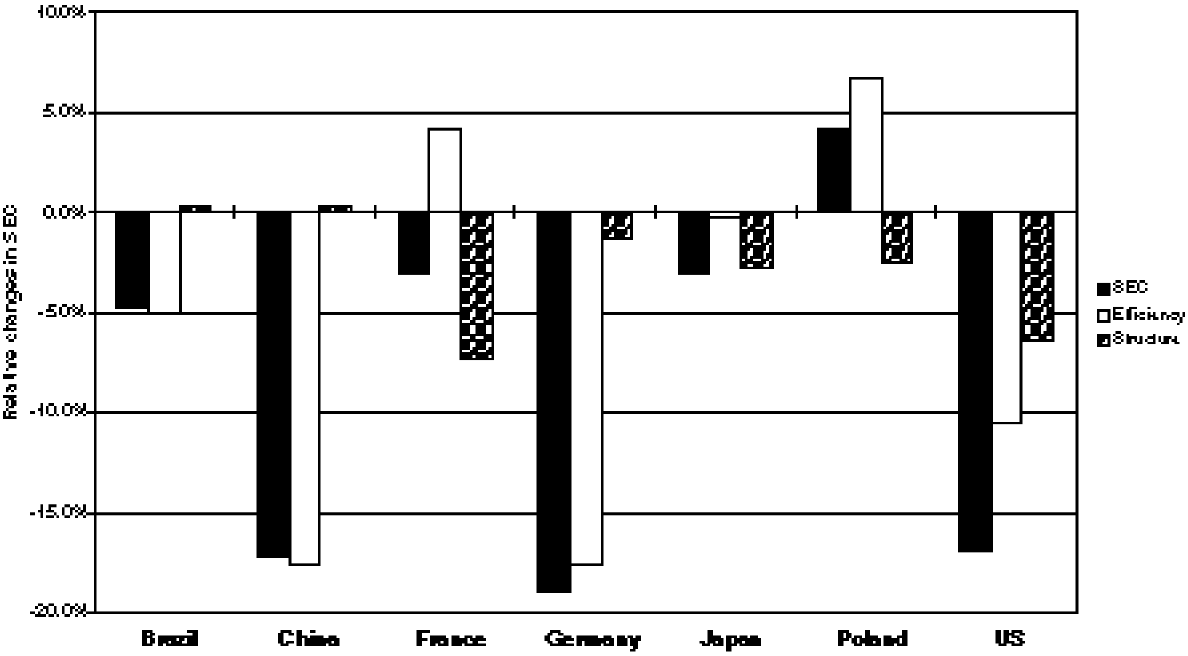

Figure 3-2. Relative changes in specific energy consumption between 1980 and 1991 and the contribution of structure and efficiency changes.

Table 3-1. Changes in SEC (expressed in primary energy use per tonne of crude steel (tcs)) between 1980 and 1991 and the influence of structure and efficiency developments in seven countries (relative changes in percents).

Country (GJ/tcs)	SEC 1980 (GJ/tcs)	Product mix (GJ/tcs)	Efficiency (GJ/tcs)	SEC 1991
Brazil	31.2	0.1 (+0%)	-1.5 (-5%)	29.7 (-5%)
China	51.3	0.2 (+0%)	-9.0 (-18%)	42.4 (-17%)
France	24.9	-1.8 (-7%)	1.1 (4%)	24.2 (-3%)
Germany	22.6	-0.3 (-1%)	-4.0 (-18%)	18.3 (-19%)
Japan	21.7	-0.6 (-3%)	-0.1 (-0%)	21.0 (-3%)
Poland	26.9	-0.7 (-3%)	1.8 (7%)	28.0 (4%)
USA	32.0	-2.1 (-6%)	-3.4 (-11%)	26.6 (-17%)

Note: The figures are based on an electricity generation efficiency of 33% across countries during the studied period.

3.3 Structure/efficiency analysis

The share of secondary (EAF) steelmaking is used as an indication of the changes in the structure (process mix) in the structure/efficiency analysis. Figure 3-3 depicts the actual SEC and the “best practice” SEC for 1980 and 1991 relative to the share of secondary (EAF) steelmaking for the U.S. and Poland. The differences in process mix between the countries are depicted clearly, as well as the changes over time. The U.S. has a relative high share of EAF steelmaking, while Germany and Poland have relative low shares (see Table 1-1). The differences between the SEC and SEC_{BP} reflect the potential energy savings, relative to the “best practice” technologies. Table 3-2 presents estimates of the potential energy savings. For most countries the two points for each year are converging, i.e. increased efficiency and reduced potential savings (e.g. China, Germany, and the U.S.). For Japan the efficiency has remained nearly constant, while for France and Poland the efficiency seems to have decreased, although modestly. The 1991 potential for energy savings, using best practice technology is estimated at 43% for Poland (see Figure 3-3 and Table 3-2).

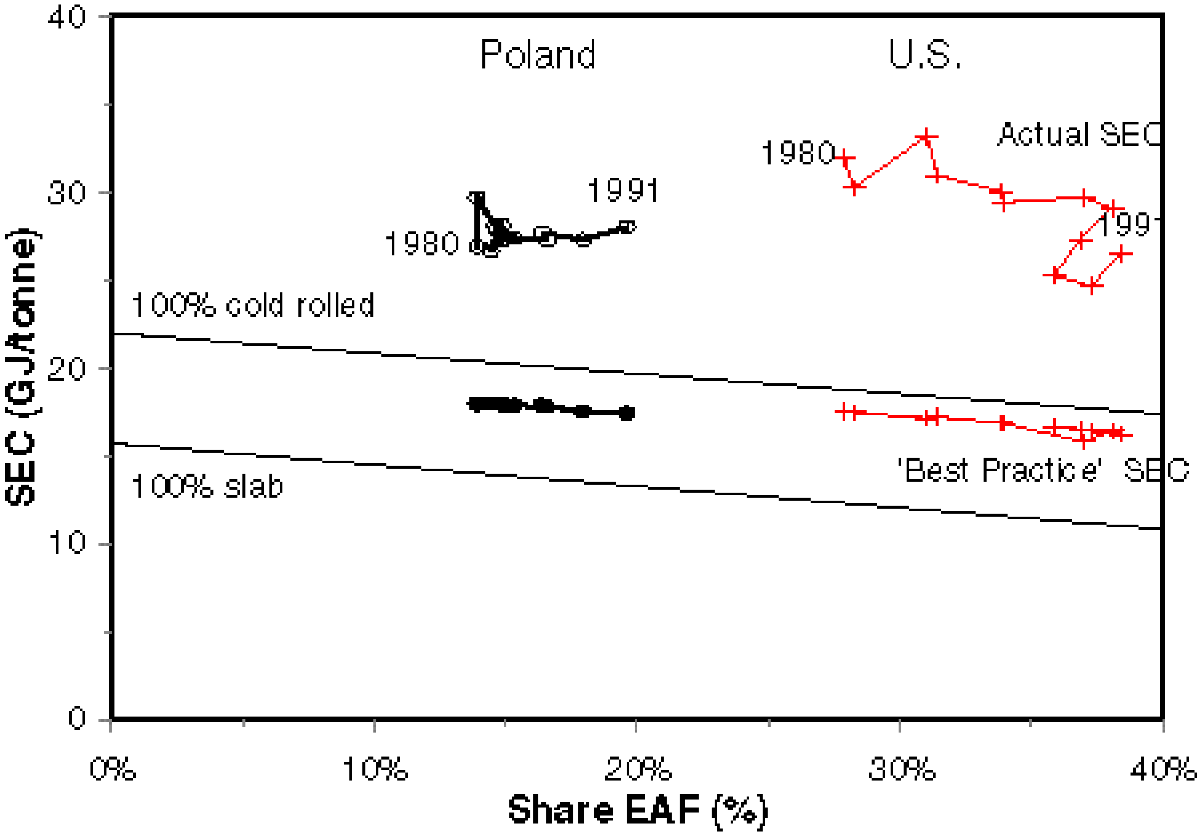

Figure 3-3. Actual and "best practice" specific energy consumption for 1980 and 1991 relative to the share of secondary (EAF) steelmaking for Poland and the U.S.

Table 3-2. Estimates of the energy efficiency improvement potentials (expressed as primary energy) in the selected countries, relative to the "best practice" technologies (see Table 2).

Country	SEC 1991 (GJ/tcs)	SEC "Best Practice" (GJ/tcs)	Potential Savings (%)
Brazil	29.7	16.0	46%
China	42.4	15.8	63%
France	24.2	16.2	33%
Germany	18.3	16.7	9%
Japan	21.0	16.0	24%
Poland	28.0	16.1	43%
U.S.	26.6	15.2	43%

3.4 Discussion of country-specific trends

Crude steel production in Brazil grew at an average annual rate of 3.6% between 1980 and 1991. Even though the structure of the Brazilian steel industry became slightly more energy-intensive due to an increasing share of BOF, the SEC dropped from 31.2 GJ/tonne to 29.7 GJ/tonne, due to increases in efficiency. The gains were unevenly distributed among plants (Henriques 1995). Investments in energy efficiency were low in Brazil during the first half of the 1980s due to economic uncertainties. Substantial long term investments in modernization of plants (including new investments in energy efficiency) began in the late 1980s with the beginning of the privatization of the steel industry.[3] The extension of the time series and analysis of SEC to more recent years might reflect the effect of this new investment.

In China steel production increased at an average rate of over 6% per year, leading to a growth in capacity utilization and construction of new capacity. Steel is produced in small, inefficient plants as well as in large state-owned integrated "key plants"(Worrell 1995). Currently about 70% of crude steel is produced in the so-called "key-plants". Between 1981 and 1990 China had several energy efficiency programs for the heavy industry (Sinton and Levine 1994). Our analysis showed strong reductions in the SEC of 17%, from 51 GJ/tonne to 42 GJ/tonne, due almost entirely to improvements in efficiency. Under these programs investments were made in increased waste heat recovery, continuous casting, fuel gas recovery, industrial boilers and furnaces, and scrap processing (Liu et al. 1994). The continuous casting ratio increased in this period from 6% to 27% of the total crude steel production (IISI 1992). The 1991 potential for efficiency improvement using 'best practice' technology is estimated at 63%.

In France, energy intensity increased in the early years of the study period, especially between 1981 and 1982. However, over the entire period, the SEC decreased slightly from 25 GJ/tonne to 24 GJ/tonne as a result of structural change towards more secondary steel (from 16% to 29%). The continuous casting ratio increased from 42% to 95% in the analysed period (IISI 1992). Energy efficiency was reduced between 1980 and 1991 which may be explained by increased hot metal charge rate in BOF steelmaking, from 78% in 1980 to 83% in 1991 (see note 2) The relatively increased pig iron production leads to a higher SEC. The 1991 potential for efficiency improvement using 'best practice' technology is estimated at 33%.

In Germany a small shift to a less energy-intensive product can be observed, through a slight increase in secondary steelmaking (from 16% to 20%) partly offset by increased production of cold rolled steel. The SEC decreased 1.7%/yr on average, dropping from 23 GJ/tonne to 18 GJ/tonne, partly due to a doubling of the continuously cast steel ratio from 46% in 1980 to 90% in 1991. The use of hot metal in BOF steelmaking changed slightly from 78% to 80% (IISI 1996b). Important energy efficiency measures implemented during the study period were increased recovery of BOF converter gases, closing of last open hearth furnace (OHF) capacity, increased electricity production through top gas power recovery turbines at the blast furnaces, and heat recovery at the EAF, sinter plant and furnaces (Aichinger 1993). The 1991 potential for efficiency improvement using 'best practice' technology is estimated at 9%.

In Japan the observed SEC decreased approximately 3% over the 11 year period, falling to 21 GJ/tonne. Changing product mix contributed to the majority (90%) of this change through increased production share of EAF and increasing pig iron imports, while the real efficiency increase was only modest (see Table 3-1). The most important contribution to the energy savings seems to be the increase in continuous casting from 59% in 1980 to 94% in 1991. The hot metal use in the BOF-steelmaking was nearly constant at 92-93%. While on the same hand the imports of pig iron quadrupled to 3.8 Mtonnes in 1991 (equivalent to 5% of the domestic pig iron production) (IISI 1992). Accounting for these imports the actual energy consumption of the Japanese iron and steel industry would have increased approximately 0.5% to 2.5% in 1980 to 1991, respectively, if the pig iron would be produced in Japan itself. The 1991 potential for efficiency improvement using 'best practice' technology is estimated at 24%.

In Poland steel production collapsed, decreasing by 46% over the period 1980-1991, due to the economic restructuring processes in Eastern Europe. This has lead to a considerable decreased capacity utilization, especially in primary steelmaking. In Poland the continuous casting ratio is very small, equivalent to 4% of total steel production in 1980 and increased to 9% in 1991, and more recently to 12% in 1994 (IISI 1996a). The SEC increased slightly during the study period from 27 GJ/tonne to 28 GJ/tonne. The most important structural developments in steelmaking were the decreasing importance of OHF steelmaking (from 47% to 25% of steel produced in the studied period), and the increased importance of EAF steelmaking (from 14% to 21%). The latter change has led to a less energy intensive product mix.

In the U.S., both structural change and efficiency improvement contributed considerably to the decreasing SEC, which dropped from 32 GJ/tonne to 26.5 GJ/tonne over the study period. The most important change in product mix is the growing share of secondary steelmaking from 27% to 38% of total steel production. Crude steel production in the U.S. decreased dramatically in the beginning of the 1980s, and remained constant at around 80 Mtonnes, with an upswing between 1988 and 1990 to around 90 Mtonnes. Efficiency improvement can be explained mainly by the increasing continuous casting ratio (from 20% in 1980 to 75% in 1991), and the closing of inefficient OHF steelmaking (the production share decreased from 12% to 2% in the period 1980-1991). The hot metal use in the BOF has increased slightly from 72% to 76% (IISI 1996b).

4. Opportunities and Measures for the Iron and Steel Industry in Poland

Physical indicators make it possible to identify opportunities and technologies for energy efficiency improvement. By comparison to energy intensity trends in other countries useful conclusions can be drawn with respect to effective measures. The international comparison has shown that the Polish iron and steel industry is one of the least efficient of the analysed countries. The international comparison also showed that energy intensity has decreased in some countries, especially Germany, but also China and the U.S. In this section we discuss how the results of the comparison can be used to identify measures to improve the energy efficiency of the steel industry in Poland.

The reasons for the high SEC in Poland were the obsolete technology, e.g. low continuous casting ratios and a relatively high share of OHF capacity (see Table 1-1), as well as decreased capacity utilization. Figure 4-1 depicts the main trends in the production structure. Even though there has been a trend toward decommissioning OHF capacity the share is still high (15%), and EAF production is only taking up 22% (IISI 1996a). Polish steel plants generally have small capacities. In Poland 22 steel plants exist, of which only two have capacities of over 3 Mtonnes/yr (e.g. Huta Katowice and Huta in Lenina). Reconstruction plans were developed in the 1970's that included the construction of large capacity plants such as Huta Katowice, as well as 10 EAF plants. Huta Katowice was built to concentrate the production in Silesia and to close small old plants around Katowice. However, other reconstruction plans were cancelled and only short term plans were executed. Therefore, various OHF-steel plants still exist that have no integrated pig iron production (Serjeantson *et al.* 1988). Pig iron is therefore transported over large distances, increasing energy losses for reheating. The high ingot casting ratio and separated production locations also lead to material losses and hence energy losses. In addition, energy and material losses are high in hot rolling. It is more difficult to find data on the efficiency of the various processes. The small size of the blast furnaces seems to be one of the reasons for the relative high coke input in blast furnaces (Van Wees et al. 1986). Generally, it seems that energy consumption is higher in all processes compared to Western countries. The pig iron and steel plant capacity utilization has been reduced to 60-70%, increasing energy use further. It is unlikely that the industry will reach full capacity in the near future.

The example of the U.S. in the early 1980's showed that reduction of overcapacity can be used to close obsolete technology such as OHF-capacity. Energy intensity of integrated plants can be decreased in Poland by closing small inefficient plants. In iron production, old small plants should be considered first, e.g. the integrated steel plants with capacities less than 2 Mtonnes (and most often with OHF steelmaking capacity). In steel production, old facilities with stand-alone OHF-capacity should be considered for closure. In secondary steelmaking, future production should be concentrated in the relative modern EAF-plants, of which some have refining capacity and continuous casting facilities, e.g. Huta Jednoś́c, Huta Nowotko, and Poldi works.

Successful modernisation strategies have reduced the energy intensity in Germany, Japan, US, as well as in China in the 1980's. Modernisation involved implementation of continuous casting, decommissioning of OHF-capacity, and increased energy recovery. In Poland, implementation of continuous casting in remaining facilities should have priority, resulting in savings of up to 1.1-1.7 GJ/tcs (WEC 1995), as well replacing OHF-capacity, e.g. Huta in

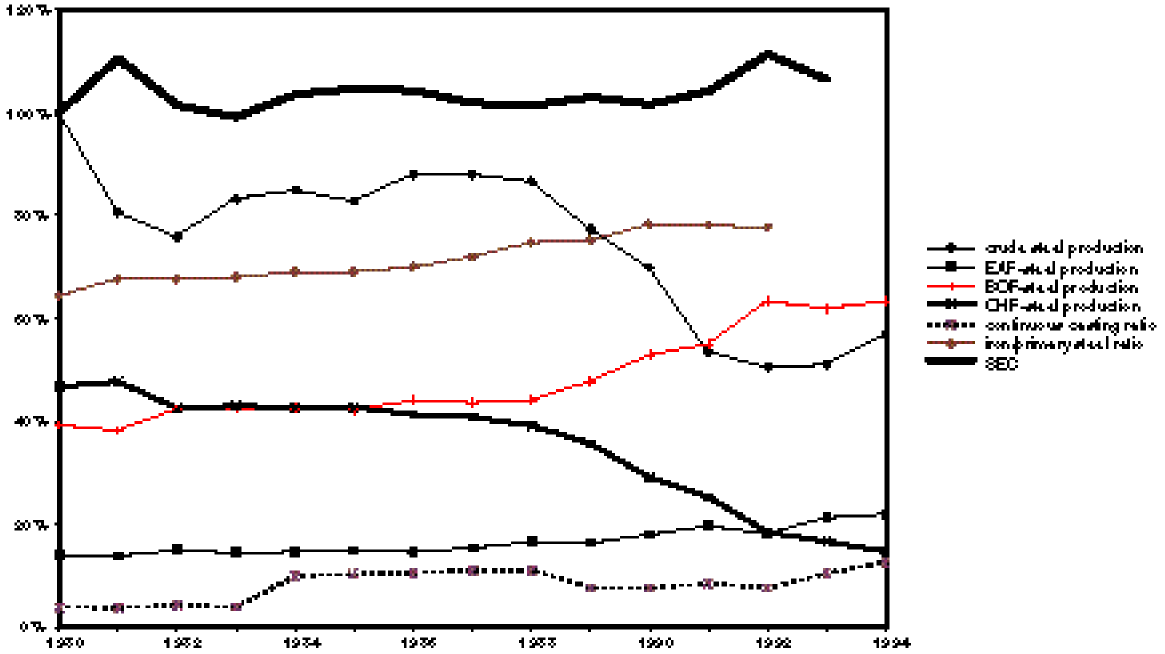

Figure 4-1. Structural development of the iron and steel industry in Poland for the period 1980 - 1994. The development is depicted relative to the 1980 situation.

Lenina, Huta Katowice. The analysis has shown that closing of OHF-capacity and introduction of continuous casting have been the main reasons for energy savings in Germany, Japan, and the US. In China the construction of modern plants and the introduction of continuous casting appear to be the main measures. Detailed study of the policies and conditions in these countries is needed to design an effective policy for Poland.

International assistance could help with the restructuring of the Polish steel industry, instead of pursuing small projects that have little or no impact on the economic viability of the industry, as well as with development of state-of-the-art technology, facilitation of long-term energy efficiency and environmental improvements, and attention to the social consequences, especially in the regions involved. Current projects seem to focus on small measures (Kuipers 1996) without a strategic vision for the Polish steel industry and economy.

5. Conclusions

We analysed the energy consumption of the iron and steel industry in seven countries for the period 1980 to 1991. We examined the trends in these countries and compared the energy efficiencies of steel production over time. Using a decomposition analysis based on physical indicators for production, we decompose the changes over time to more carefully examine intra-sectoral structural changes, including the use of secondary steelmaking and efficiency improvements. The selected countries show varying trends, although the observed SEC decreased in almost all countries. Efficiency improvement played a key role in the observed energy savings in Brazil, China, Germany, and the U.S., while structural changes were the main driver for energy savings in France and Japan. Even though the structure became slightly less energy-intensive, energy efficiency decreased in Poland due to the economic restructuring process.

Physical indicators make it possible to identify opportunities and technologies for energy efficiency improvement. By comparison to energy intensity trends in other countries useful conclusions can be drawn with respect to effective measures. Especially Germany, but also China and the U.S., have effectively reduced energy intensity. In Poland we identified major opportunities for energy efficiency (e.g. reduction of over-capacity by decommissioning of OHF-capacity, small blast furnaces, and integration and concentration of production capacity, following the example of the U.S. as shown in the decomposition analysis), reduction of material losses (e.g. increasing continuous casting levels, as was shown to be successful in Germany and other OECD countries) and implementation of modern technology, such as continuous casting, increased recovery of fuels (coke oven, blast furnace and BOF-gas), heat and power (blast furnace).

6. Endnotes

1. Data are for the former Federal Republic of Germany only.
2. In the analysis of the SEC_{BP} (and the weighting factors used) we assumed a hot metal charge rate of 90% in the BOF. For most countries the hot metal charge is lower (except for Japan), which leads to lower pig iron use per tonne of steel, and hence a lower SEC_{BP} for a country or year. As we have assumed a constant charge rate changes in the hot metal charge rate are accounted as an efficiency effect in the decomposition analysis. For most countries the hot metal charge rate has not changed much (IISI 1996b), and hence in most cases we underestimate the potential for energy savings. However, in France for the period 1980-1991 the hot metal charge rate increased from 78% to 83% (IISI 1996b), which might be due to improving product quality and increasing scrap prices. This an important reason for the decrease in energy intensity in France.
3. Personal communication from M.M. Costa, Federal University of Rio de Janeiro, Brazil.

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