Scandinavian Journal of Metallurgy 2001; ***30****: 420–425*
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SCANDINAVIAN
JOURNAL OF METALLURGY
ISSN 0371-0459

CO_2 emissions of the Swedish steel industry

Hans Sandberg[1], Rune Lagneborg[2], Birgitta Lindblad[1], Helén Axelsson[1] and Lars Bentell[1]

[1]*The Swedish Steel Producers Association, Box 1721, 111 87 Stockholm, Sweden*
[2]*The Swedish Institute for Metals Research, Drottning Kristinas väg 48, 114 28 Stockholm, Sweden*

The energy consumption and CO_2 emission of Swedish production of flat and long products of structural steel have been assessed by means of LCI data from the IISI study.

Two general factors reduce the expenditure of energy and CO_2 emission in Swedish production of both flat and long products: energy efficient steel processes and extremely low CO_2 emissions for generation of electricity.

For flat steel products also two specific features contribute to their low energy consumption and CO_2 emission, viz. the use of magnetite iron ore instead of hematite and a product programme with a uniquely large share of high strength steels. The latter allows significant weight savings in end products, thus resulting in global net reductions of energy consumption and CO_2 emission.

Even when transport of Swedish products to export markets are included, the Swedish figures are more favourable than those of steels manufactured domestically in their respective markets.

Key words: energy, carbon dioxide, Swedish steel industry, LCI data.

Accepted for publication 29 June 2001

1. Background

1.1 The Kyoto protocol

The emission of carbon dioxide and its influence on the climate were discussed in the UN conference in Rio 1992. But already four years earlier the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP) established the Intergovernmental Panel on Climate Change (IPCC). In the Rio conference the participating countries decided that the greenhouse effect is a real problem and must be taken care of. Six years later 175 countries had ratified this Climate Convention (United Nations Framework Convention for Climate). The third meeting of the parties of this Convention was held in Kyoto 1997. In this meeting it was agreed to decrease the emissions of six greenhouse gases with 5.2% in the industrialised countries from 1990 to 2010 (average 2008–2012). The countries in the EU have to decrease their emissions by 8%. Within the EU the countries have made their own division based on the possibilities for the different countries to decrease the emissions. As a result of this Sweden is allowed to increase its emissions by 4%. The six gases in the Kyoto Protocol are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6). The most important of these is carbon dioxide. To be able to add the influence of the different greenhouse gases an index GWP, Global Warming Potential, has been introduced. The Kyoto protocol is supposed to be the first step towards even more stringent restrictions on the emissions of greenhouse gases. However, we are still awaiting the acceptance of the final protocol in all its details.

1.2 The share of CO_2 emissions of the steel industry

The reduction of iron ore to hot metal in blast furnaces and other reduction processes is almost entirely based on coal products. By necessity the steel industry therefore emits large amounts of carbon dioxide. In 1997 the total global emission of carbon dioxide was about 23 billion tons. Of this the steel industry emits 1.2 billion tons or 5%, including all upstream emissions (for production of raw materials etc) and electricity production [1]. The emission of carbon dioxide in Sweden was 56 million tons the same year, including transports and electricity production in Sweden [2]. Of this 5.8 million tons originated from the steel industry. If external deliveries of process gases, steam and hot water are excluded, the emission of carbon dioxide from the steel industry is reduced to about 5 million tons or less depending on which emission factor is used. This means that the carbon dioxide emission from the steel industry in Sweden is approximately 9%. This higher percentage than the world average of carbon dioxide emission is due to the fact that Swedish electricity is generated to about 90% in hydro power plant and nuclear power plants resulting in a very low total CO_2 emission.

2. Energy consumption and CO_2 emissions of the steel industry "world wide"

Steel is predominantly produced by two process routes, the blast furnace route with up to 25% scrap input and the electric arc furnace route with normally 100% scrap input.

In 1996 the Board of Directors of IISI initiated a global LCI (Life Cycle Inventory) on "Steel Industry Products" [1]. The goal of the project was to produce world wide LCI data for steel industry products. The functional unit, which enables the system inputs and outputs to be quantified and normalised is one kilogram of steel products at the factory gate. The study is focused on carbon and low alloy steels (alloy content <2%). The study is a cradle to gate LCI study. That is, it covers all the production steps from raw materials in the earth crust (i.e. in the cradle) to finished products ready to be shipped from the steelwork (i.e. the gate). It includes the production and transportation of raw materials, energy resources and consumables used in the steelworks. In addition, the recovery of steel industry by-products outside the steelworks are taken into account. It does, however, not include the manufacture of downstream products, their use, end of life and scrap recovery schemes.

2.1 Blast furnace route for low carbon steel

Table 1 below show the total primary energy consumption and CO_2 emission for blast furnace route production of one ton of hot rolled coil and plate. Adopting the production values of 1996 from the IISI LCI database [1], the averages, maximum and minimum values of 35 sites located around the world have been calculated.

2.2 Electric arc furnace route for carbon steel

In table 2 below the total primary energy consumption and CO_2 emission are shown for production of one ton of sections and rebar-wire rod-engineering steel by the electric arc furnace route [1].

Table 1. Total primary energy consumption and CO_2 emission (global average) [1]

Plant	Total primary energy consumption, MJ/ton steel [1]			Total CO_2 emission, ton CO_2/ton steel [1]		
	Average	Max.	Min.	Average	Max.	Min.
Global average						
Coil and plate (35 sites)	25 500	31 700	21 450	1.97	2.60	1.61
SSAB Coil and plate	25 500	–	–	1.97	–	–

Table 2. Total primary energy consumption and CO_2 emission (global average) [1]

Product	Total primary energy, MJ/ton steel			Total CO_2 emission, ton CO_2/ton steel		
	Average	Max.	Min.	Average	Max.	Min.
Global average						
– Section (4 sites)	11 200	15 300	8 600	0.54	0.77	0.31
– Rebar – wire rod eng. – steel (10 sites)	11 800	16 400	5 000	0.59	1.08	0.15
Fundia						
– Section	10 300	–	–	0.4	–	–
– Rebar – wire rod – eng. steel	8 900	–	–	0.3	–	–

3. Energy consumption and CO_2 emissions of the Swedish steel industry

3.1 Blast furnace route for low carbon steel

Sweden is producing in the plants of SSAB approximately 3 Mton/year of structural strip and plate steels. The total primary energy consumption and the CO_2 emission for this steel production is according to the IISI LCI database 25 500 MJ and 1.97 ton CO_2, respectively, per ton of hot rolled coil and plate (average). However, the steel production of SSAB deviates strongly from other international producers of the same products in two respects, viz.

– An exceptional high magnetite content of the iron ore used in SSAB's process

– A product programme with an outstanding high percentage of high strength steels.

These two factors are not accounted for in the figures above. As will be shown below, they will lower the net consumption of energy and the CO_2 emission considerably and accordingly the IISI LCI figures for SSAB have to be modified.

3.1.1 Reduced energy consumption and CO_2 emission by use of magnetite iron ore

Iron ore is delivered to the steel plants either in the form of fines or pellets, depending on the quality of the original ore and on the operational practices at the steel plant. Pellets represent globally less than one third of the total iron ore delivered to the steel plants. The sintering of iron ore fines always takes place in the steel plants. Generally the mining companies perform the pelletising although some steel companies have their own pelletising plants (e.g. Hoogovens and Kobe Steel). The SSAB production is based to 100% on pellets produced by the Swedish mining company LKAB. This iron ore has an outstanding high magnetite content, which requires less heat energy for pelletising than more commonly used hematite ores. In the IISI LCI database [1] the energy consumption for pellets production is based on hematite ores and standardised to 1 950 MJ per ton of pellet. The LKAB pellets consume 500 MJ energy per ton. To produce 1 ton of hot rolled coil requires 1.38 ton of pellets. The energy consumption to produce 1 ton of hot rolled coil at SSAB, calculated according to the IISI LCI database, has therefore to be reduced by 1.38(1 950–500)=2 000 MJ per ton of coil. Applying the relation between energy consumption and CO_2 emission of table 1 this energy reduction can be estimated to correspond to a reduction of the CO_2 emission of 0.15 ton CO_2/ton coil.

3.1.2 Reduced energy consumption and CO_2 emission by use of high strength structural steels

The application of high performance materials saves resources and reduces the environmental load by the following reasons:

- Reduced material consumption directly in the design and construction of an end product.
- Prolonged life of the end product whereby the rate of material consumption is reduced.
- High performance materials enable the design and construction of machines and processes with higher energy efficiency.

The use of high strength structural steels as a replacement of ordinary structural steels decreases the steel consumption according to the first point and this results in a net reduction of the energy consumption and the CO_2 emission. Moreover, when high strength steels are used in vehicles, which is a large and expanding market for these steels, the reduced weight also lowers the fuel consumption. Hence, high strength steels contribute also significantly to energy savings and reduced CO_2 emission in end products. However, in the following we will only consider effects according to the first point.

The relationship between strength and price for modern high strength steels, HSS, is very favourable. In load carrying applications where the increase in strength could be utilised, the reduced material consumption usually lowers the cost of the final product. This saving for the end user of the product is indeed a prerequisite for a sustainable success and growth of the HSS usage. The driving force for development and use of HSS is therefore strong and the Swedish steel industry takes a leading position ''world wide'' in this product niche. The consumption growth of these steels is high and the Swedish production of high strength flat products increases by 5–15% annually. An indication of the potential in material saving, which is possible to obtain by replacing ordinary steels with a strength of 250–300 MPa, is the strength levels reached by steel development so far:

– strip 1500 MPa
– plate 1100 MPa.

The share of high strength grades of the Swedish production of hot and cold rolled strip steels is about 50% whereas the average share in Western Europe is estimated to 6–10%. For the global steel production the share is even lower than for Europe. This implies that the production and ultimate application of Swedish high strength steels result in a global net saving of material and therefore a global net reduction of energy consumption and CO_2 emission. In this context it is of special interest that these steels are unalloyed or microalloyed (<0,1% alloying) and generate therefore hardly any additional environmental loads in production of alloying elements. The enhanced strength of the steels is primarily obtained by controlled rolling and cooling.

The savings in material- and energy consumption, by utilisation of high strength steels from the Swedish steel industry, are often considerable. Through real case studies it has been found that if the steel strength is increased by a factor "x" the weight can be reduced by a factor $1/\sqrt{x}$. By utilising the existing product programme of high strength flat products, which this industry can offer today, it has been shown that the utilised strength can be doubled in known applications with the customers.

With the existing sales volumes of high strength steels (50% of 3 Mton) this means that the reduction in steel consumption for the customer will be approximately 620 000 ton per year (1.5 Mton $/(1/\sqrt{2})$–1.5 Mton). The energy consumption and the CO_2 emission to produce 1 ton of flat products is 25 500 MJ and 1.97 ton CO_2, respectively (table 1). Hence, with these sales volumes of HSS the net global energy consumption and CO_2 emission is annually reduced by 4.4 TWh (1.6×10^{10} MJ) and 1.2 Mton CO_2, respectively. The Swedish total production of flat products is 3 Mton per year. Thus, relative to this overall production volume the reductions in energy consumption and CO_2 emission will be 5 300 MJ and 0.41 ton CO_2, respectively, per ton of steel.

3.1.3 Energy consumption and CO_2 emissions of Swedish strip and plate steel production

We can now calculate the real energy consumption and CO_2 emission for the Swedish production of structural strip and plate steels, corrected for the high magnetite content of the iron ore used in the process and the outstanding high share of HSS of the product programme. These calculations are shown in table 3 below.

In comparing the energy consumptions and CO_2 emissions of strip and plate production in Sweden and globally, credit should also be given to the share of high strength steels of the 35 global sites, tables 1 and 3. Although the share of these 35 steel works located around the world is likely to be lower we will use the figure for works in Western Europe, 8% (the middle of the interval estimated, section 3.1.2). Furthermore we will assume that the strength levels offered by these 35 sites will be as high as those of Swedish flat products i.e. the utilised strength can be doubled. Carrying out the same type of calculation as in 3.1.2 we arrive at the following reductions in energy consumption and CO_2 emission for the 35 global sites, 850 MJ and 0.065 ton CO_2, respectively, table 3.

Export of Swedish steel to Europe, North America or Far East Asia expends fuel for the transportation and hence increases the energy consumption and CO_2 emissions [3]. By adding the CO_2-quantities consumed for transportation to different markets the total CO_2 emissions for Swedish hot rolled coil landed in

Table 3. Energy consumption and CO_2 emissions for production of one ton of hot rolled coil and plate

Plant	Total primary energy consumption, MJ/ton coil and plate			CO_2 emission, ton CO_2/ton coil and plate		
	Average	Max.	Min.	Average	Max.	Min.
Global average [1]	25 500	31 700	21 450	1.97	2.60	1.61
– corr. for prod. program	−850			−0.065		
	24 650			1.90		
SSAB	25 500	–	–	1.97	–	–
– corr. for magnetite	−2.000	–	–	−0.15	–	–
– corr. for prod. program	−5 300	–	–	−0.41	–	–
	18 200			1.41		

Table 4. CO_2 emissions for production of one ton of hot rolled coil and plate in Sweden by the BF route and transportation to different markets

CO_2 emissions for production (see table 3) ton CO_2/ton coil and plate	Europe ton CO_2/ton coil and plate		North America ton CO_2/ton coil and plate		Far East Asia ton CO_2/ton coil and plate	
	Transport [3]	Landed	Transport [3]	Landed	Transport [3]	Landed
1.41	0.03	1.44	0.15	1.56	0.30	1.71

different locations around the world can be calculated. The results are shown in table 4 below. By comparing these figures with the global average in table 1, we can conclude that even the CO_2 emissions for Swedish steel transported to the most distant markets are lower than the world average.

The market distribution of SSAB's strip products is approximately: Sweden 30%, Europe (excl. Sweden) 50%, and USA and other countries 20%. These market shares combined with the total CO_2 emissions for the various geographic locations give the following average CO_2 emission for SSAB's strip products landed in different markets:

$$0.30\times1.41+0.50\times1.44+0.20\ (1.56+1.71)/2 = \mathbf{1.47\ t\ CO_2}/\mathrm{t\ coil}$$

In this calculation we have assumed that the CO_2 emission for transportation to the Swedish market can be neglected.

3.2 The electric arc furnace (EAF) route for carbon steel

Swedish steel industry is producing 0.5 Mton/year of long products in carbon steel grades. The production is concentrated to Fundia's two plants in Smedjebacken and Boxholm. The total primary energy consumption varies between 8 900 to 10 300 MJ/ton depending on final product. CO_2 emissions vary between 0.3 to 0.4 ton CO_2/ton product, see table 2.

The steel grades of Fundia are similar to those of the average plant in the IISI LCI-study. Hence, in this case no correction for a high share of high strength steel products is justified. The products are sold mainly on the North European market. Therefore only a minor correction is made for the CO_2 emission due to transportation from Sweden to the market (+0.02 ton CO_2/ton product).

From this calculation we can estimate the total CO_2 emission for production of one ton of long products in Sweden (Fundia) and transport to the market. The figures are shown in table 5 below. Again comparing these figures with the global average in table 2 we find that the CO_2 emission for Swedish long products landed in its primary export market is lower.

Table 5. CO_2 emission for production of one ton of long products in Sweden through the electric arc furnace route and landed in the European market

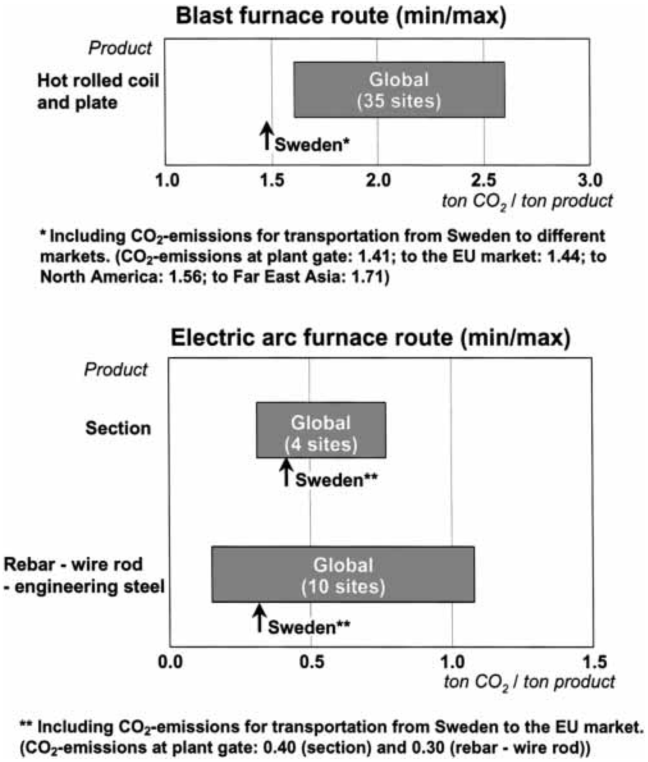
Products	ton CO_2/ton steel
Fundia	
– Section	0.42
– Rebar- wire rod- eng. steel	0.32

4. Conclusions

The CO_2 emissions for production of Swedish flat and long steel products including the emissions associated with the transportation to various export markets are assembled in fig. 1, together with the corresponding figures of the best steel producers world wide (35 and 14 sites for the blast furnace and the EAF route, respectively). These are represented in the diagrams by the scatter band of the figures. As we can see the emissions for the Swedish steel products are in general significantly lower than those of steel produced domestically in the various markets. Even the emission of Swedish steel exported to Far East Asia is on a par with the best global producers.

The lower emissions of Swedish flat products are due to the following factors:

- Energy efficient steel processes.
- The use of magnetite iron ore instead of hematite lowers the energy consumption in the pelletising process and thereby also the CO_2 emission.



* Including CO_2-emissions for transportation from Sweden to different markets. (CO_2-emissions at plant gate: 1.41; to the EU market: 1.44; to North America: 1.56; to Far East Asia: 1.71)

** Including CO_2-emissions for transportation from Sweden to the EU market. (CO_2-emissions at plant gate: 0.40 (section) and 0.30 (rebar - wire rod))

Fig. 1. CO_2 emissions for Swedish carbon steel products compared to the same products from the best plants in each market.

- A product programme with a uniquely large share of high strength steels allowing significant weight savings in end products, thus resulting in global net reductions of energy consumption and CO_2 emission.

In the lower part of fig. 1 the CO_2 emissions of Swedish long products landed in the European market and European steel consumed domestically are compared. Again the figure for Swedish steel is more favourable. In this case it is due to the following features of Swedish EAF steel production:

- Extremely low CO_2 emissions for generation of electricity in Sweden (50% hydro power plus 50% nuclear power).
- Energy efficient steel processes.

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