Industrial Energy Efficiency in Light of Climate Change Negotiations: Comparing Major Developing Countries and the U.S.

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ABSTRACT

In light of the commitments accepted within the Framework Convention on Climate Change there is an increasing need for useful information on energy consumption and energy efficiency. Governments can use this information in designing policies to reduce greenhouse gas emissions and prioritizing energy savings options. International comparisons of energy efficiency can provide a benchmark against which a country's performance can be measured and policies can be evaluated.

A methodology for international comparisons of industrial energy efficiency was developed by the International Network on Energy Demand analysis in the Industrial Sector. In this paper this methodology is used to analyze the energy efficiency of two energy-intensive industries in major developing countries. Energy consumption trends are shown for the steel and cement industry and an analysis is made of technologies used. In light of the Byrd-Hagel resolution, which states that the U.S. will not ratify any climate treaty unless it also mandates commitments to limit greenhouse gas emissions for developing countries, the energy efficiency in the two sectors is compared to that of the U.S.

The analysis shows that in the iron and steel sector South Korea and Brazil are more energy-efficient than the U.S, while Mexico has achieved a comparable energy efficiency level in recent years. For cement, South Korea, Brazil and Mexico are the most efficient countries analyzed. In recent years, China, and especially, India appear to have achieved energy efficiency levels, more or less comparable to that of the U.S. In light of data constraints, however, further analysis is required.

Introduction

Background

At the 1992 Earth Summit in Rio de Janeiro over 150 Countries signed the United Nations Framework Convention on Climate Change (FCCC, or 'Climate Convention'), aiming to protect the climate by stabilizing "greenhouse gas concentrations ... at a level that would prevent dangerous anthropogenic interference with the climate system" (UN 1992). The Climate Convention emphasizes that developed countries are mainly responsible for historical and

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current emissions of greenhouse gases (GHG), and that developing country emissions must be allowed to grow so that their social and development needs can be fulfilled. Therefore, although both developed and developing countries accepted commitments, a quantified commitment to limit anthropogenic GHG emissions was only established for developed countries (article 4.2).

At the third conference of the parties to the Convention in Kyoto in 1997 (COP-3) legally binding emission reduction targets were set for the so-called Annex-I countries (OECD[2] countries and the countries of Eastern Europe and the former Soviet Union). In accordance with the Convention, the Kyoto Protocol did not outline new commitments for non-Annex-I countries in addition to the ones included in the FCCC (UN 1992; UN 1997). The omission of emission limitation targets for developing countries at COP-3 was opposed by the U.S., which called for 'meaningful participation of major developing countries' (USIA 1997). Earlier that year the U.S. Senate approved the Byrd-Hagel resolution outlining the conditions under which the U.S. Senate would ratify the Kyoto Protocol. The Senate resolution states that "*the United States should not be a signatory to any protocol..., which would mandate new commitments...for Annex I Parties, unless the protocol also mandates new specific scheduled commitments to limit or reduce greenhouse gas emissions for Developing Country Parties within the same compliance period*" (Byrd-Hagel 1997).

In general it is acknowledged that developing countries have a role to play in abating global climate change, since their emissions are rapidly growing (see e.g. (UN 1992; WRI 1997)). One of the major growth areas in developing countries is the production of energy-intensive bulk materials, because of currently low per capita consumption of these bulk commodities. Per capita cement consumption, for example, in the developing countries analyzed in this paper, is a factor 2 to 6 times lower than the OECD average. For steel, the per capita consumption is even 2 to 20 times lower than the OECD average (Price, Phylipsen and Worrell 1999a; Price et al. 1999b). It is often assumed that energy efficiency in developing countries is lower than in developed countries, especially in discussions related to joint implementation, the clean development fund and emission trading. Therefore, improving energy efficiency in these sectors is considered to be an important option for limiting energy-related greenhouse gas emissions. International comparisons can be a tool in benchmarking a country's performance against that of other countries or to prioritize emission reduction options either domestically or abroad. Such comparisons are also very relevant in deciding on whether or not to submit projects under the Clean Development Mechanism.

Scope

In this paper we focus on energy-related greenhouse gas emissions from the production of two major bulk commodities, steel and cement, analyzing energy use per tonne of product in the U.S. and a number of key developing countries. We will analyze how the energy efficiency in these sectors in developing countries relates to that in the U.S. The steel and cement sectors are chosen, because they are projected to be the largest energy-consuming industrial sectors in developing countries in the future[3] (Price et al. 1998).

[2] Excluding newcomers Mexico and South Korea

[3] in 2020. As a whole, the chemical industry is expected to consume more energy than the cement sector. However, the chemical industry consists of numerous different products, of which even the most important (ethylene, ammonia, chlorine) account for far less energy consumption than cement.

Section 2 describes the iron & steel industry and the cement industry. Section 3 explains the methodology used for international comparisons of energy efficiency in industry. In section 4 this methodology is applied to the U.S. and a number of major developing countries. Section 5 extends the analysis to energy-related GHG emissions. Finally, the discussion and conclusions are presented in sections 6 and 7.

Description of the Iron & Steel and Cement Sectors

The Iron & Steel Industry

In the iron & steel industry the main processes are ironmaking and steelmaking. Pig iron is produced by reducing iron ore with coke (or coal) in the blast furnace. The pig iron serves as an input for the basic oxygen furnace (BOF) or open hearth furnace (OHF), in which it is converted into crude steel. The BOF route is the more efficient of the two and is the most predominant process used to produce primary steel worldwide (IISI 1990). A recently developed process, smelt reduction, combines coal gasification with the reduction of iron oxides to produce pig iron. Smelt reduction presents one of the most advanced ironmaking technologies available, making coke production and ore agglomeration redundant.

Another route to produce steel is the electric arc furnace (EAF) route, predominantly used to produce secondary steel (using scrap only). Secondary EAF steel is less energy-intensive than BOF steel because coke production and iron production can be omitted. The EAF can also be fed with iron from the direct reduction (DR) route. DR (or sponge) iron is used to enhance steel quality or if high quality scrap is scarce and/or expensive.

Crude steel is converted into finished products by casting, either in ingots or continuously. Continuous casting is the more efficient option. Cast steel is processed in hot rolling mills, and can subsequently be rolled into thinner products in the cold rolling mill.

Global steel production in 1997 reached 800 Mt, with China (109 Mt) surpassing both Japan (105 Mt) and the U.S. (99 Mt) to become the world's largest steel producer (IISI 1999). In this paper we analyze the 5 largest developing country producers (in 1995): China, South Korea, Brazil, India, Mexico. Furthermore, we also include South Africa (20th largest producer worldwide), because of a number of remarkable characteristics of the South African steel industry. Figure 1.a presents the production of crude steel over time in the selected developing countries and the U.S., showing that the U.S., after a sharp decline in the late 1970s to early 1980s now has comparable production levels to China. The other countries have significantly lower production levels (data as listed in INEDIS: from 1970-1985 (OECD 1995); from '86-'95 (IISI 1997); except for China: '71-'93 (MMI 1994), for '94-'95 (IISI 1997) and for South Africa: (IISI various years)).

The Cement Industry

Two important processes in producing cement are clinker production and the blending of clinker with additives to produce cement. Clinker production is the most energy-intensive step in the production of cement. Clinker is produced by burning a mixture of mainly limestone ($CaCO_3$), silicon oxides, aluminium oxides and iron oxides. Production can take place using the wet process, the dry process or an intermediate form (referring to the conditions of raw materials processing). The dry process is more energy-efficient than the wet process. After the melt has cooled down, clinker is blended with gypsum and, depending on the desired product, fly ash, blast furnace slag or other additives. Product qualities depend on the relative amount of clinker in the cement, which can range from 30-95% (Dutron 1993).

World cement production reached 1450 Mt in 1995 (Hendriks et al. 1999). This paper focuses on the top-6 developing country producers (China, India, South Korea, Thailand, Mexico and Brazil) and the U.S. The historical production rates for these countries are shown in Figure 1. The figure shows especially rapid growth in China (note that China is plotted against the secondary, vertical axis) and also in India, South Korea and Thailand.

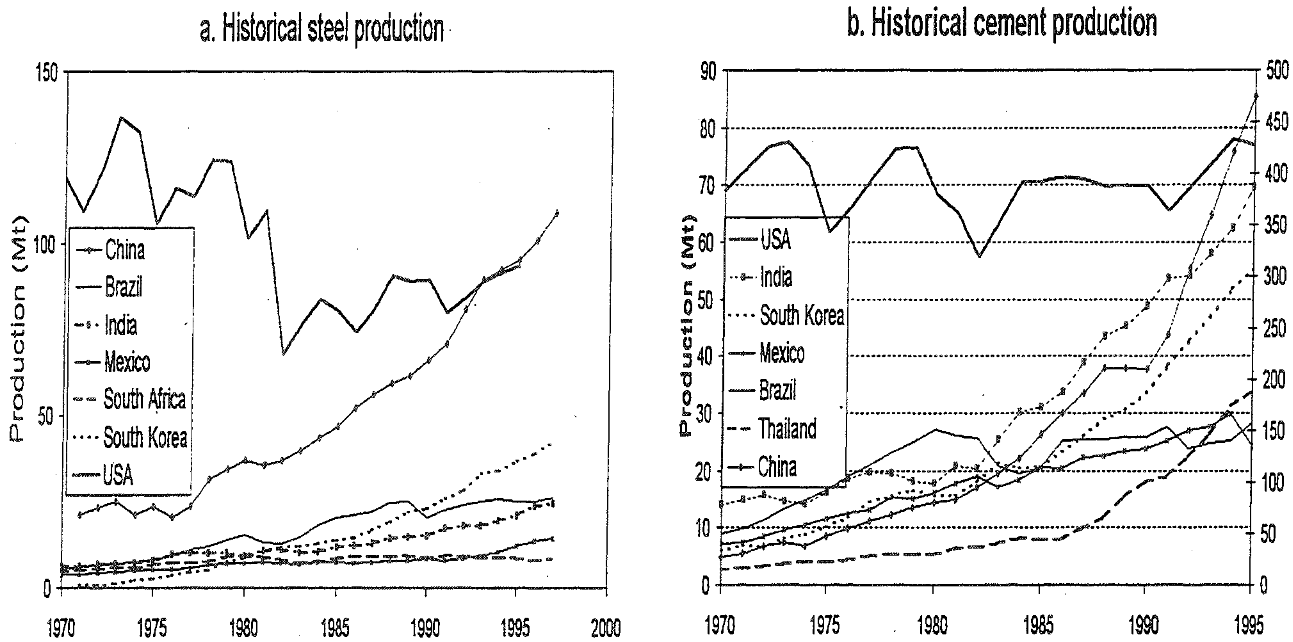

Figure 1. Historical production of steel (a) and cement (b) for the U.S. and major developing countries. Note that for cement China is depicted on the right axis (data as listed in INEDIS: from 1970-'85 (OECD 1995), from '86-95 (IISI 1997); except for China: '71-'93 (MMI 1994), for '94-'95 (IISI 1997) and for South Africa: (IISI v.y.))

Methodologies for International Comparisons of Energy Efficiency

Comparing energy efficiency between countries is difficult because of differences in economic structure. Also within a specific country, the economic structure can change over time. At a sectoral level, we define sector structure as the product mix within a sector, accounting for differences in product quality (e.g. primary vs. secondary steel) and factors that affect product mix. Feedstock and process type are not considered to be indicators of sector structure, unless they influence the product mix (or product quality) (Phylipsen, Blok and Worrell 1998).

The methodologies described here were developed through collaboration with international energy efficiency experts (Martin et al. 1994; Phylipsen et al. 1996) and described in the Handbook on International Comparisons of Energy Efficiency in the Manufacturing

Industry (Phylipsen, Blok and Worrell 1998). The methodologies are currently being used within the International Network on Energy Demand analysis in the Industrial Sector (INEDIS 1999).

Sector Structure

In the iron & steel industry, product mix, defined as the share of iron, slabs, hot rolled steel, cold rolled steel and wire, is an important structural indicator. Furthermore, feedstock (scrap vs. iron ore) is considered to be a structural indicator because product quality can be influenced by the scrap input due to contaminations from other metals (i.e. product mix is influenced) and the amount of scrap available to a steel plant may be a limiting factor in choosing between iron and scrap (i.e. not amenable by the steel producer). This means that for iron and steel both product mix and feedstock mix have to be taken into account into the calculation of the sectoral reference SEC (Phylipsen, Blok and Worrell 1998).

A structural indicator in the cement industry is the clinker content of cement, because of, again, product quality and the availability of alternative additives (e.g. blast furnace slag). Also, imports and exports of the intermediate product (i.e. clinker) are a part of sector structure. Both aspects, clinker content and import/export streams, can be incorporated into one single structural indicator: the clinker production to cement production ratio.

It must be noted that changing sector structure can also lead to a decrease in CO_2 emissions. In the steel industry increasing the share of secondary steel will reduce energy consumption and therefore emissions. In the cement industry the effect is even twofold. Decreasing the clinker content in cement will reduce energy consumption, and thus energy-related emissions, but also process emissions resulting from the production of clinker. However, in this analysis we focus on energy efficiency as a way to decrease emissions because of time and space limitations.

Energy efficiency comparisons

Because of the influence of sector structure on energy intensity cross-country or cross-time comparisons cannot be made based solely on trends in the absolute value of indicators such as the specific energy consumption (SEC, energy consumption per tonne of product) for each country. In our methodology we compare actual SECs with a reference SEC[4] that is based on the given sector structure. This means that both the actual SEC and the reference SEC are similarly affected by changes in sector structure. The difference between the actual and reference SEC is used as a measure of energy efficiency, because it shows which energy efficiency level is technically achievable in a country with a particular sector structure. The relative differences, or ratios, between actual and reference SEC can be compared between countries. Usually, this is done by calculating an energy efficiency index (EEI): the ratio between actual SEC and reference SEC. A country's reference SEC is established by calculating the weighted average of the reference SECs of individual processes and/or products present in that country.

[4] Here defined as the SEC of the best plant observed worldwide, valid for most regions or countries. Such a best plant is defined for each process and the sectoral value is calculated as the weighted average, based on the shares of the various processes and products

International Comparison

In this section we compare the iron and steel industry and the cement industry in the selected countries. First, we discuss the technology base of these two industries, focussing on some key technologies. Then we compare energy intensities of steel and cement production. For one recent year we show how structure influences energy consumption, and the development of the energy efficiency index over time is presented.

Technology Base

Figure 2 shows the technologies used in the iron and steel industry and the cement industry. Figure 2.a depicts the share of energy-inefficient open hearth furnaces in total steel production in each of the countries analyzed. It shows that the share of OHF has declined sharply over the years for all of the countries analyzed. Only China and India currently have OHF-based capacity left. The Figure also shows that South Korea, South Africa and Brazil phased out OHFs before the U.S. Furthermore, the phase out in OHF-based capacity occurred more rapidly in most of the developing countries analyzed than in the U.S. This is partly caused by the higher rate of new construction in developing countries, in order to meet the fast growing demand. In most of the countries, however, also the absolute level of OHF-based production is declining.

Figure 2.b shows the share of the electric arc furnace in total steel production. The share of EAF can be used as an approximation of the share of secondary steel production (i.e. steel recycling). According to Figure 2.b Mexico has a relatively high share of EAF-based production of about 60% in recent years. The figure also shows that the U.S., South Africa and, in recent years, South Korea have a similar share of EAF steel of about 40%. The other countries have a lower share of EAF-based capacity of between 20-30%. This can partially be explained by limited scrap availability (because of currently low per capita steel consumption rates) and poor reliability of electricity supply (the main energy input for EAFs) in countries such as India (Schumacher and Sathaye 1998). It must be noted that the EAF process can also be combined with DR Iron, resulting in primary steel. This frequently occurs in developing countries. In South Africa and India DRI comprises about 15% and 20% of iron production respectively[5], while in Mexico the share of DRI is even about 50% (IISI 1997).

Figure 2.c shows the penetration of an efficient casting technology: continuous casting. It shows that South Korea, South Africa, Mexico and Brazil had already implemented continuous casting on a significant scale, before this technology became relevant in the U.S. steel industry. South Korea and South Africa still have a higher share of continuous casting in total steel production than the U.S., while Mexico and Brazil are currently regaining ground they lost during the economic crisis in the mid-1980s. The importance of continuous casting is still lower in India and China, but implementation rates in recent years in these countries are comparable to those in the U.S. (OECD 1993; IISI various years; IISI 1997; IISI 1999b).

The smelt reduction process is currently only used on a commercial scale in South Africa and South Korea. A plant using the COREX smelt reduction process was built in Pretoria in 1986, while a second is scheduled to come on line shortly (Iscor 1999). Another COREX unit is being built in India. No COREX units are currently used or planned in the U.S.

[5] partly coal-based DRI production

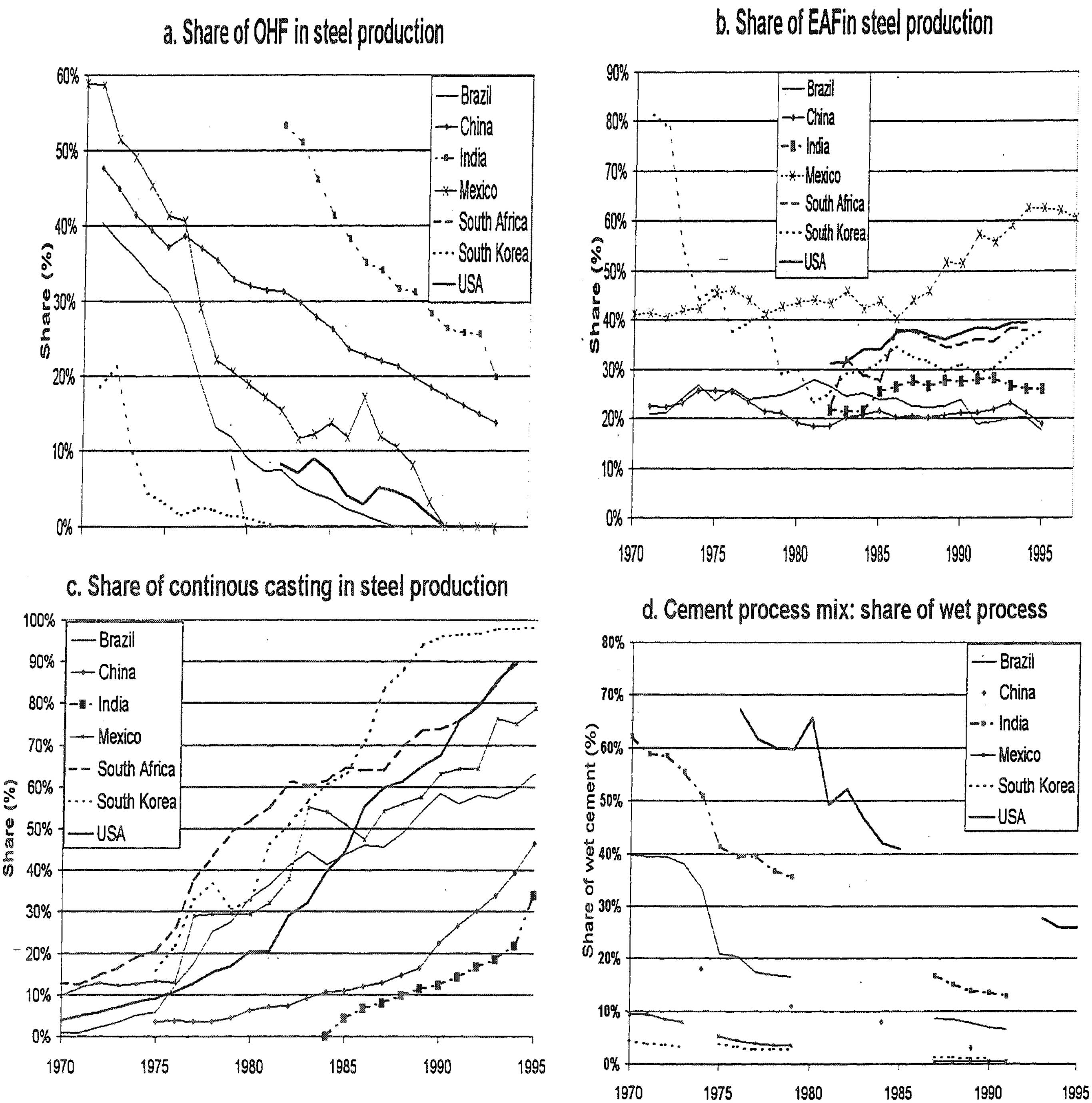

Figure 2. Technologies employed in the iron and steel industry: a) the share of OHF and b) the share of EAF in total steel production; c) the share of continuous casting in total steel production and the cement industry: d) the share of the wet process in total cement production. Data on processes used in cement production were not available between 1985-1992. (data as listed in INEDIS. For steel: (OECD 1993; IISI 1997; IISI 1999b0. For cement: all countries (Cembureau v.y.); Brazil (Schaeffer 1995); China (Sinton 1996); India (AIS 1996; International Cement Review 1998; TERI v.y.); Mexico (INEGI 1994); USA (PCA 1996))

For the cement industry, an important energy efficiency indicator is the share of wet process in total cement production. The wet process is the less efficient process, so a lower share of wet process plants will lead to higher overall efficiency. Figure 2.d shows the share of wet process-based cement capacity in the selected countries. The U.S. has the highest share of wet process-based cement capacity of all the countries analyzed. For South Korea, Mexico and China the wet process comprises less than 5% of total capacity in recent years. For Brazil and India, the wet process accounts for about 10 and 15% respectively, while for the U.S. about 25% of cement capacity is wet process-based. It must be noted that the share of the wet process in actual production can be different. For both India and Brazil wet processes account for about 2% of total cement production. The faster phase out of wet capacity in developing countries is partly caused by the high rate at which new capacity is constructed. In most countries, however, the absolute level of wet process-based production is also declining (Cembureau v.y.). It must be noted that, especially in China, a large part of the non-wet plants are shaft kilns, which in general produce a lower quality cement than wet or processes.

Energy Intensity of Steel and Cement Production

Energy consumption per tonne of products is a simple measure of the energy intensity of an industry (including both effects of energy efficiency and sector structure). Figure 3 shows the primary energy intensity for the iron and steel industry[6] (a) and the cement industry (b).

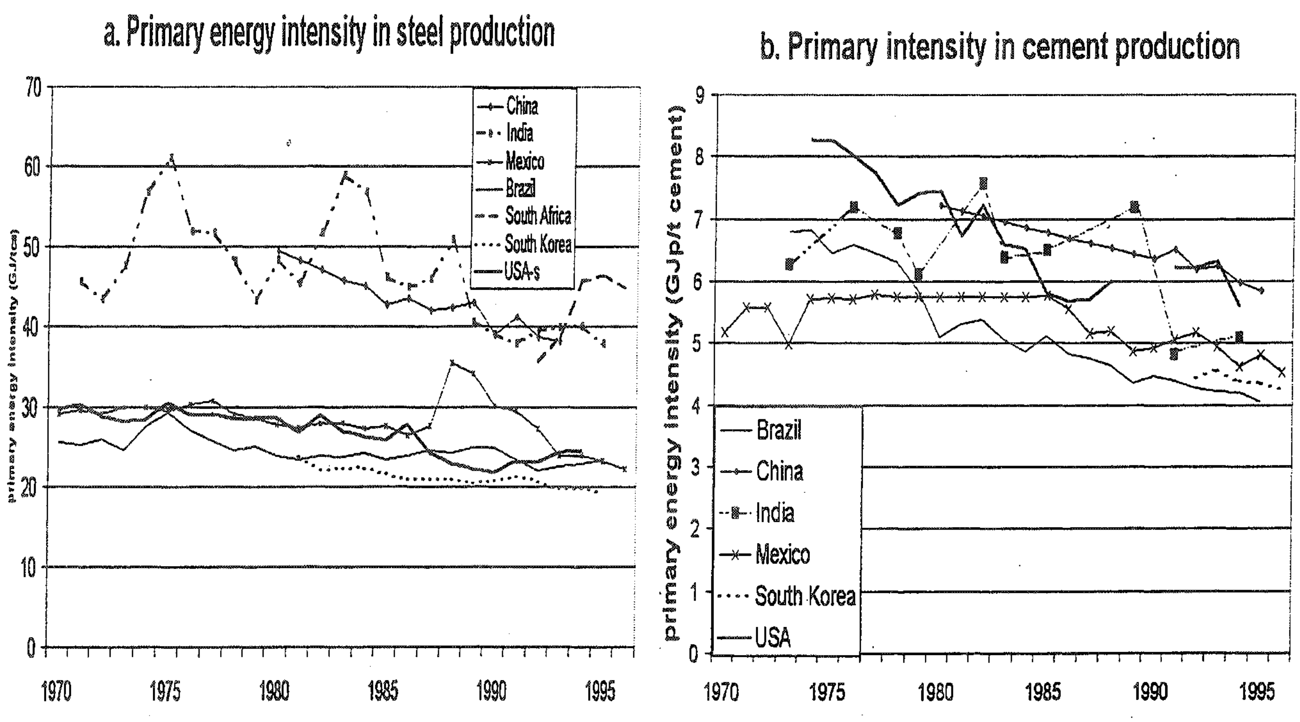

Figure 3. Primary energy intensity in a) steel production and b) cement production. Primary energy consumption is calculated using an electricity generating efficiency of 30%. Data as listed in INEDIS (For steel: all countries (OECD 1993; IISI v.y.; IISI 1997; IISI 1999b); China (MMI 1994; Sinton, 1996); India (IEA v.y.); Mexico (NEB Mexico v.y.); South Africa (NEB South Africa v.y.); U.S. (MECS v.y.)[7]. For cement: all countries (Cembureau v.y.); Brazil (Schaeffer 1995); China (Sinton 1996); India (AIS 1996; International Cement Review 1998; TERI v.y.); Mexico (NEB Mexico v.y.; INEGI 1994); U.S. (MECS v.y.; PCA 1996))

[6] excluding coke production

[7] MECS is only published once every three years. Data for the intermediate years are interpolated based on the SEC

Note that these intensities do not take into account structural differences between countries. In the steel industry South Korea is shown as the country with the lowest primary energy intensity[8] in recent years, followed by Brazil, Mexico and the U.S.[9]. China[10], India and South Africa have higher primary energy intensities. In the cement industry primary intensity in recent years is more closely grouped together than in the case of the iron & steel industry. South Korea is again one of the countries with the lowest primary energy intensity[11], along with Brazil and Mexico. India appears to have reached comparable energy efficiency levels in recent years. The U.S. and China show higher primary energy intensities in cement production.

Energy Efficiency Comparisons

Part of the differences shown in Figure 3 is caused by differences in sector structure between countries. Also, part of the trend can be caused by changes in sector structure over time, such as an increased share of secondary steel. By applying the methodologies described in section 3, we account for these effects. Figure 4 shows structure/efficiency plots for the iron and steel industry and the cement industry for 1994 as an example. In both cases the actual SEC and the reference-SEC are shown. The distance between the two is an indication of the relative energy efficiency of each of the countries. Note that the graph may look different for other years (see Figure 5 for trends in the relation between SEC and reference SEC).

For the iron and steel industry, the SECs are depicted as a function of the share of EAF in total steel production (Figure 4.a). This is used (for representation purposes only) as an approximation of secondary steel production (a higher share of EAF leads to less coke production, iron production and primary steel production, and therefore a lower SEC, depicted by the diagonal reference-SEC line in Figure 4.a). It shows that South Korea and Brazil are the most energy efficient, followed by Mexico and the U.S. The energy efficiency in China and India is substantially lower.

Figure 4.b shows the structure/efficiency plot for the cement industry, depicting SEC as a function of the clinker to cement production ratio. The solid diagonal line here represents the reference SEC at different clinker/cement ratios. The fact that South Korea's actual SEC is below the reference-SEC indicates that our reference values for individual processes are out-of-date, as is confirmed by Park (1998), who lists actual SECs for South Korean plants that are below the values we have used in this analysis. The figure does indicate, however, that here too South Korea has the lowest efficiency improvement potential, followed by Mexico and Brazil. India, the U.S. and China are less efficient.

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[8] Primary energy consumption is calculated using a 30% electricity generating efficiency for all countries in order to exclude differences in generating efficiency between countries. In this way we are comparing the efficiency in the iron & steel industry between countries, instead of a mixture of the efficiency of the iron & steel industry and the efficiency of electricity generation. The actual efficiencies of the countries analyzed range between 27 and 33%. It must be noted that Brazil has a high share of hydro power in electricity generation. Depending on the conventions used, also a higher efficiency can be calculated.

[9] For the U.S., a double counting occurs in the published iron and steel industry data. Blast furnace gas (produced out of coke) is included in the reported energy consumption, in addition to coke. Our preliminary estimate is that the actual U.S. energy consumption is about 15% lower than the reported values in MECS. Therefore, 15% is subtracted from the specific energy consumption for steel.

[10] For China energy consumption includes 'living energy', energy used in workers' residences, and mining energy. This energy use, estimated at 6% by Ross and Feng (1991), is subtracted from the reported energy consumption.

[11] For Korea data is only shown as of 1990, because for earlier years purchased electricity was not included

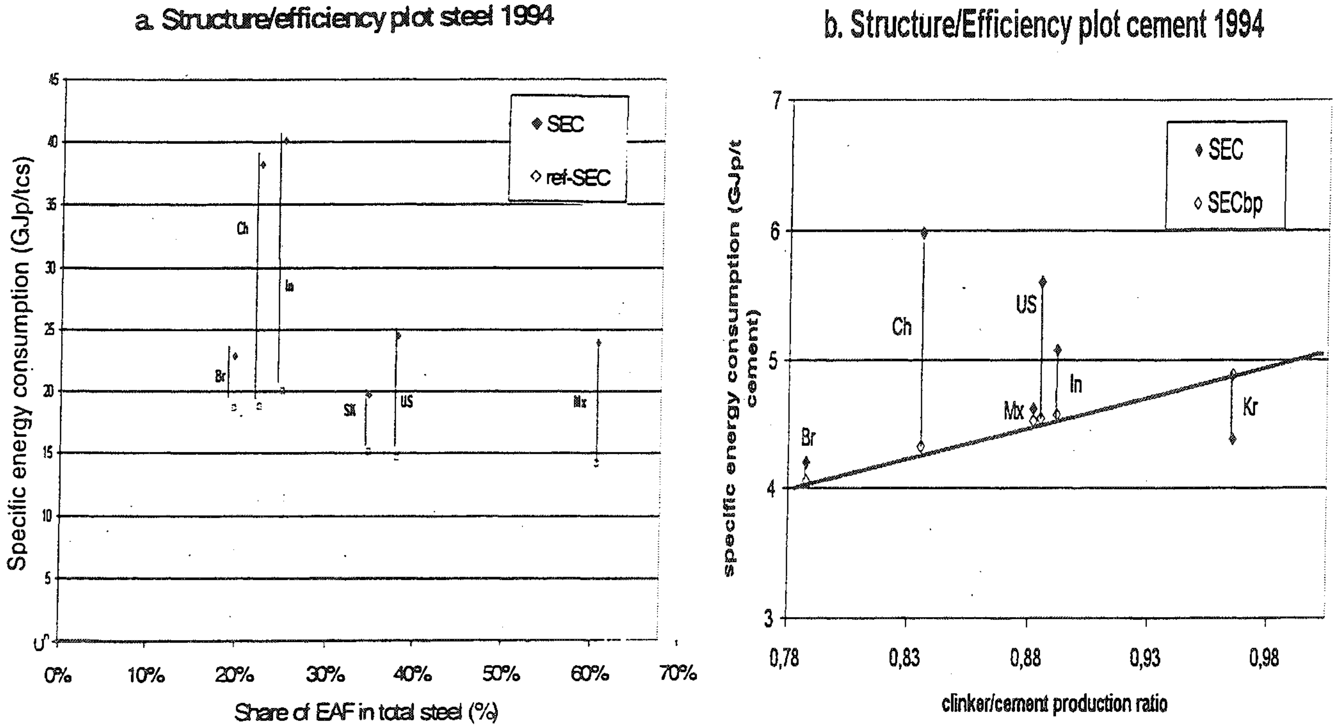

Figure 4. The structure/efficiency plots for iron and steel (a) and cement (b). The upper points represent actual SEC, while the lower points represents the reference-SEC. The diagonal lines in Fig.4a represent the reference-SEC at various shares of EAF and the possible range of the product mix[12]. South Africa is not included in Fig. 4a because of a lack of data on product types. The solid lines indicate energy efficiency improvement potentials. The diagonal in Fig.4b shows the reference-SEC at various clinker/cement ratios. Note that these figures only represent one year, and the situation can be different for other years. Indexed time series are shown in Figure 5

The relative difference between the actual SEC and the reference SEC as depicted in Figure 4 (i.e. the ratio of actual SEC to reference SEC) is a measure of energy efficiency[13] that can be compared between countries. This ratio is called the energy efficiency index (EEI) and its development over time is shown in Figure 5 for iron and steel (a) and cement (b). An EEI of 100 represents an energy efficiency level of best plant technology.

For *steel*, there is a clear difference between the EEI (Fig.5a) and the primary energy intensity shown in Figure 3.a, with South Korea and Brazil more clearly separated from Mexico and the U.S. in Fig 5.a, and China and (in recent years) India coming much closer. This means that the lower position of the U.S. and Mexico in Figure 3.a was mainly caused by a less energy-

[12] Generally, a country's bp-SEC will be in between these two diagonal lines, depending on the exact product mix. However, the lines are calculated assuming that EAFs are fed with scrap. In countries, that have a substantial share of DRI as EAF input, the bp-SEC of DRI is added to that of EAF steel. Therefore, the position of such countries (such as Mexico and India here) appears shifted to the right, and might end up above the two bp-lines. For the calculation of the energy efficiency indicator, however, this has no consequences, since actual production according to both the scrap-EAF route and the DRI-EAF route are included.

[13] Note that the ratio decreases as efficiency increases. As with most of the known efficiency indicators, the energy efficiency index, in fact, depicts the inverse.

intensive industry structure, and the higher position of India and China in that same figure was mainly caused by a more energy-intensive structure.

Figure 5.b shows a less pronounced difference for the *cement* industry between the trend in primary energy intensity and the EEI. Based on Figure 5.b, South Korea is slightly more efficient than Brazil, while in Figure 3.b Brazil's primary energy intensity was lower than that of South Korea. Also, the primary energy consumption of the U.S. and China were comparable in recent years, according to Fig.3b, while Figure 5.b shows the U.S. to be somewhat more efficient.

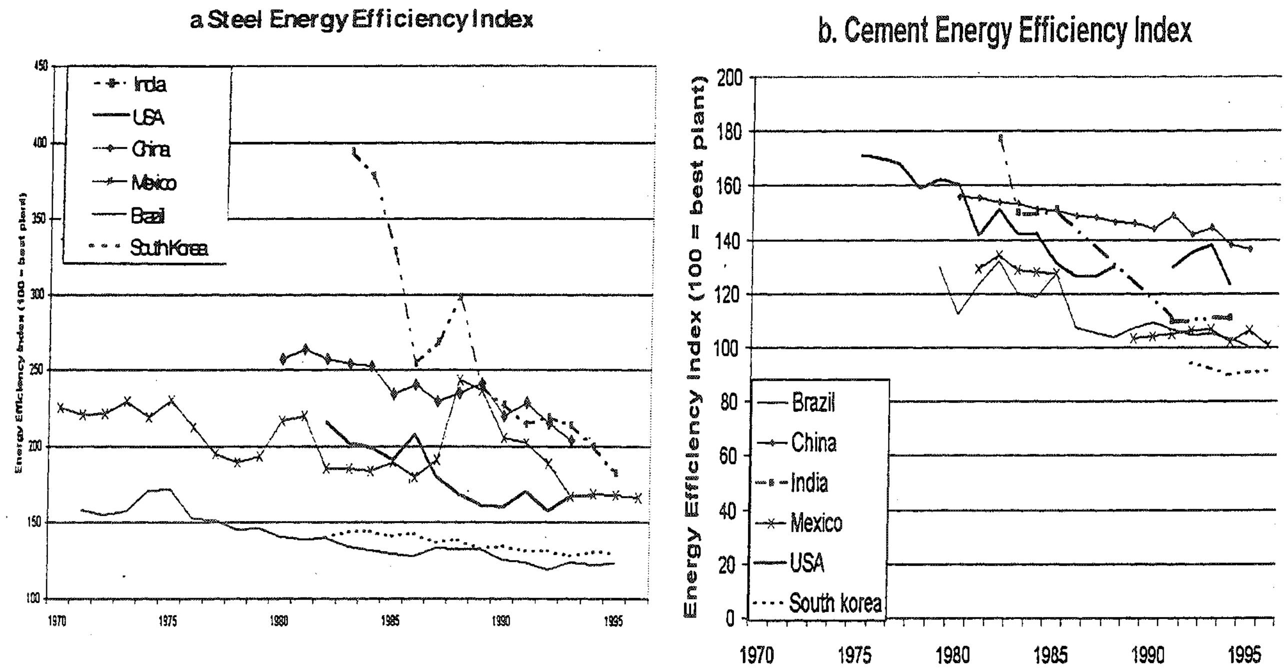

Figure 5. The Energy Efficiency Index for iron and steel (a) and cement (b). The EEI is the ratio of actual SEC to reference-SEC, in which an index of 100 represents the reference (or best plant) SEC. The further above 100 a country is, the less efficient

Carbon Dioxide Emissions

The energy-related CO_2 emissions from steel and cement production have been calculated, using IPCC carbon emission factors[14]. Emissions of electricity consumed in the production of steel and cement have been allocated to the industry, using national average emission factors for each country and for each year (INEDIS 1999).

For *iron and steel* production, China's CO_2 emissions rapidly increased to about the level of the U.S. in the 1970s. The emissions of the other countries are still substantially smaller, than those of the U.S. For 1994 total energy-related emissions for *cement* production in China, including fuel emissions, amounted to about 54 Mt C (Hendriks et al. 1999), about 6 times the current level of the U.S. India has currently reached about the same emission level as the U.S.

[14] 25.8 kg C/GJ final energy for solid fuels, 20.0 kg C/GJ for liquid fuels and 15.3 kg C/GJ for gases, 0 for biomass energy (LHV). Process-related emissions are not included.

and South Korea about half of that. The other countries' emissions are still substantially smaller than those of the U.S.

It must be noted that the figures mentioned above include a number of differences, including different production volumes. Differences in production volume can be eliminated by calculating the carbon intensity, i.e. the carbon emissions per tonne of product. For recent years the carbon intensity of *iron and steel* production has been about the same for South Korea, Brazil, Mexico and the U.S., although the carbon intensity of the U.S. steel industry has been increasing since 1990. The carbon intensity of steel production in China, India and South Africa is substantially higher. For *cement*, Brazil has the lowest carbon intensity of the countries analyzed, partly due to its high share of hydro power. Following are Mexico and South Korea, at about the same level. In recent years, the U.S. and India have achieved about the same level of carbon intensity, substantially higher than that of the other countries, with China still slightly higher.

It must be noted that carbon intensity still includes structural differences and changes, as was the case for the primary energy intensity (Fig.3). To account for that, a carbon intensity index can be calculated, comparable to the energy efficiency index (see section 3.2). The carbon intensity index is not shown graphically here because of space limitations, but the results are very similar to those shown in Figure 5 for the energy efficiency index. Both are very different from the trend in the primary energy intensity and in carbon intensity. Table 1 shows total CO_2 emissions, CO_2 intensity and the carbon intensity index for steel and cement for 1994.

Table 1. Sectoral CO_2 emissions (Mt C), CO_2 intensity (t C/t) and carbon intensity index (CII) for iron and steel and cement production for 1994. In case best plant technology would have been used, the CII would equal 100

Country	Iron & steel			Cement		
	Total CO_2	CO_2 intensity	CII	Total CO_2	CO_2 intensity	CII
Brazil	9	0.36	135	1	0.05	119
China[2]	142	1.53	201	64	0.15	145
India	20	1.03	204	8	0.13	135
Mexico	5	0.44	180	3	0.08	123
South Africa	9	1.64	-[2]			
South Korea	14	0.41	141	5	0.09	98
U.S.	45	0.49	177	9	0.12	130

Notes: [1] For China steel data are for 1993, cement data are for 1994; [2] The CII for South Africa cannot be calculated because the breakdown of steel products is unknown;

Discussion

In this paper the energy efficiency of the iron and steel industry and the cement industry is assessed, using methodologies developed within INEDIS, the International Network on Energy Demand analysis in the Industrial Sector. Similar methodologies have been developed for other industrial sectors. It must be noted that in other sectors the ranking of efficient countries might be different. This, however, emphasizes the need for bottom up information on energy consumption and technology, instead of basing assumption on energy efficiency solely on geographical location.

For most of the countries analyzed here, the required data are available and gathered in the INEDIS database. Within INEDIS these data are checked for consistency, such as system boundaries, conversion factors used (e.g. LHV or HHV), etc. For a number of smaller developing countries, however, no data on energy consumption, product mix and technologies used are available within the country itself. For other countries, such as China and India, data quality might be a problem. For India the results found in this paper for the cement industry are comparable to those found by Bode et al. (1999), Schumacher and Sathaye (1998) and (Das and Kandpal 1997)[15]. It appears that for the Indian cement industry only medium size and small plants are included in both energy and production data. The not-included small plants are estimated to account for 5% of production and 10% of energy consumption (CMA 1998). Including these small plants in our analysis will result in an increase in average specific energy consumption and a decrease in estimated energy efficiency. Roughly, this will result in an increase in SEC of 5% and in the energy efficiency index of 11 points.

For the Chinese cement industry other sources list somewhat lower primary energy intensities (about 10% lower) (Zhiping and Sinton 1994; Sinton and Yang 1997). It is not clear whether small cement plants are included in those studies, as they are for China in our analysis. A 10% lower primary intensity in recent years would roughly have resulted in a decrease in the efficiency index of ten points. For steel, Zhiping and Sinton (1994) also list a specific energy consumption for key plants only, that is about 10% lower than our results. A 10% lower SEC would result in a decrease in the energy efficiency index of 20 points (on a total of about 230).

Generally speaking, the ranking of countries in terms of energy efficiency corresponds with the technology base as shown in section 4. The least efficient countries (China and India) in steel production have the highest share of OHF capacity and the lowest share of continuous casting, while the most efficient country (South Korea) has the lowest share of OHF capacity and the highest share of continuous casting. In the cement industry, the most efficient countries are the countries with the lowest share of wet process capacity. Only China is less efficient than what would be expected based on the share of wet process capacity.

Conclusions

This paper demonstrates that a number of key developing countries are equally or more energy efficient than the U.S. industry. In the steel industry, South Korea and Brazil are more efficient than the U.S., while Mexico has achieved a comparable level of energy efficiency. For cement production, South Korea, Mexico and Brazil are more efficient than the U.S., while also India appears to have become more efficient in recent years. China is the least efficient country in our analysis. The data for India and China, however, must be interpreted with care, and a further analysis of these countries is needed.

The U.S. position on climate change is that it will not ratify the Kyoto Protocol unless developing countries show meaningful participation. The key developing countries analyzed in this paper are important in the context of climate change, since they are experiencing rapid growth in production and emissions. Our analysis indicates, however, that many of these countries are producing steel and cement equally or more efficiently than the U.S. More information on the relative efficiency of other industrial sectors is essential for U.S. policy

[15] Our results are slightly higher than those of (Karwa et al. 1998), but those values are based on a limited sample size and extrapolation.

makers in light of on-going climate negotiations and potential decision-making on investments projects under the Clean Development Mechanism.

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