Differentiation of Greenhouse Gas Reduction Objectives Based on Differences in Energy Efficiencies in Heavy Industry

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ABSTRACT

This paper gives an overview of energy efficiencies in six industrial subsectors in fourteen countries in order to indicate what consequences differences in energy efficiency may have for a differentiation of commitments for reducing greenhouse gas emissions. Differentiating the burden of greenhouse gas emission reductions among Parties to the UN-FCCC has appeared in recent climate negotiations. Values for the Specific Energy Consumption were compared with structure-corrected values for a reference SEC to obtain an indication of energy efficiency. For some countries, specific energy consumption may be as high as 1.5 to 1.7 times the reference level whereas for other countries factors this factor is not higher than 1.2.

In order to establish a differentiation of commitments the room for energy efficiency improvement in each country and each heavy industry subsector was utilized with an equal share in order to achieve an overall 5% reduction of CO_2 emissions. The resulting partial reduction objectives for heavy industry vary from –15% to +20% in 2015 over levels in the late 1980s and early 1990s. The effect of these differences in total allowances is 7% to 10%.

Although the values of this exercise are preliminary – due to limited data availability – we demonstrate that it makes sense to account for differences in industrial energy efficiencies in future burden differentiation rules.

Introduction

Since global manufacturing industry (including construction) consumes 41% of today's primary energy and emits 43% of global CO_2 emissions (Price et al. 1998), its contribution to the global greenhouse gas (GHG) emissions is substantial. In December 1997, the Third Conference of Parties to the UN-Framework Convention on Climate Change (UN-FCCC) reached an agreement on quantified reduction objectives for GHG emissions in industrialized countries to be achieved in the commitment period 2008-2012. It was agreed that these objectives would differ by country. This differentiation of commitments over countries is a rather new phenomenon in environmental agreements, but it might stay in future climate negotiations for the next commitment period. However, it has turned out difficult to find a single indicator on which to base such a differentiation. A lot of different simple indicators have been proposed, such as emissions per capita or per GDP. However, none has turned out to be satisfactory as they are either politically unacceptable or considered unfair. Other rules such as marginal cost of abatement or past contributions to climate change require large amounts of data and proved to be too complex. A politically acceptable and fair differentiation of commitments would take into account reasonable economic growth rates, the structure of the economy and the potential for reducing specific GHG emission (e.g. by improvement of energy efficiency or the input of renewable energy). It then seems reasonable to take into account differences in industrial energy efficiencies. The inclusion of such national circumstance would be a typical example of the application of the polluter pays principle that has been laid down in article 3.1 of the UN-FCCC.

Background

In the negotiations preceding the Third Conference of the Parties to the UN-FCCC, European member states had to reach an agreement on a common European negotiating position. In this process, one of the inputs consisted of the results of the Triptych approach that was developed by Phylipsen et al. (1998d; 1998a). The Triptych approach aims to assess a fair differentiation of commitments taking into account national circumstances. It divides a nation's economy into three sectors: power generation, the domestically-oriented sectors (including households, transport, agriculture and light industry) and heavy industry. For each of the sectors specific guidelines were constructed to calculate partial allowances for the sector. Subsequently the partial allowances were added to get the national allowances. For the sector 'heavy industry' the allowance was based on a production growth factor and an efficiency improvement factor. Two different production growth factors were applied for the richer member states and the so-called Cohesion Fund countries (Greece, Ireland, Portugal and Spain), whereas uniform efficiency improvement rates were assumed for all member states and all industrial subsectors. Although the outcome of the calculations was satisfactory and of great use to European negotiators (Council Conclusions 1997), one drawback of the approach is that it does not take into account existing differences in energy efficiency. These differences can be substantial (Worrell et al. 1994) and industrial CO_2 reduction potentials vary accordingly. Therefore, it is necessary to refine the part of the Triptych approach covering heavy industry. Further, an extension to non-EU countries increases the usefulness of such sector approaches as tool in future global climate negotiations.

Past research

Previous work on differences in industrial energy efficiency must be considered when indicating the consequences of these differences for a fair differentiation of commitments. Much research has been carried out over the past few years with respect to industrial energy efficiencies (e.g. De Beer 1998; Farla et al. 1997; Phylipsen et al. 1998b; Phylipsen et al. 1995; Worrell et al. 1997; Worrell et al. 1995). These studies all focus on energy efficiency comparisons using indicators on a physical basis and take into account relevant international structural differences within subsectors i.e. product and/or process mix. Recently, the *Handbook on international comparisons of energy efficiency in the manufacturing industry* was published (Phylipsen et al. 1998c) The guidelines in this handbook were described previously in Phylipsen et al. (1997).

Aim and scope

This study aims to give a brief overview of efficiencies in various industrial subsectors in order to indicate consequences for a fair differentiation of CO_2 emission reductions for the year 2015, which is the middle of the next commitment period. We assume that current energy efficiency levels fairly indicate where CO_2 emission reductions are most easily attainable. Although the goal of a firm is rarely to minimize carbon emissions, firms are obvious parties to contribute to the global effort of climate change mitigation. Allowances may be agreed at the national level, but the reduction of carbon emissions will have to be realized by internal sectors of a country's economy. For highly inefficient industries a reduction will be more feasible than for more efficient industries, as the marginal cost of abatement goes up with the quantity of emissions reduced. This makes industrial energy efficiency one of the national circumstances relevant for a fair differentiation of commitments.

Factors such as the age of the facility, cost of upgrading or retrofitting or the availability and cost of alternative fuels have been left aside in this study. Incorporating these would be practically impossible. Moreover, flexible mechanisms such as joint implementation and emissions trading are strong tools to correct for differences in the cost of carbon emission reduction. The main point is that physical carbon intensity constitutes a solid base for the burden differentiation to depart from, as the physical feasibility of emission reductions is a prerequisite for the mitigation of climate change.

Furthermore, it must be emphasized here that the differentiation of commitments that results from this study only illustrates current differences in industrial energy efficiency. It covers (partial) allowances for heavy industry only and does not comprise the power generation branch and the domestic sector.

The industrial subsectors included in this study are iron and steel, primary aluminium, the petrochemical industry, ammonia, pulp and paper and the cement industry. According to the World Energy Council (1995) the iron and steel industry consumed 14% of 1990 global industrial energy, the petrochemical industry accounted for 9%, the pulp and paper industry uses 4% and the cement industry 5%. For the primary aluminium and the ammonia industry no global figure was available, but within the European Union these subsectors consume 2% and 3% of industrial energy respectively (Worrell 1994). Important energy-intensive subsectors that have been omitted due to lack of data include the petroleum refining industry (3% within the EU) and to a lesser extent the chlorine industry (0.6%).

The countries included here are Belgium, Brazil, Finland, France, Germany, Ireland, Japan, the Netherlands, Norway, Poland, Portugal, South Korea, the United Kingdom and the United States. These countries had at least 20% of their energy use in heavy industry covered by a varying number of industrial subsectors for which data on production and energy consumption were available for at least two subsectors of heavy industry. We define heavy industry as comprising the chemical industry, iron and steel, the non-ferrous industry, non-metallic minerals (building materials) and the pulp and paper industry.

Structure of the paper

This paper is divided in two main parts. In the first energy efficiencies in the six subsectors are discussed. This section includes definitions of activity, efficiency and structure, energy consumption and the reference level of the specific energy consumption. It gives a brief description of the industrial processes included, an overview of structural indicators for each subsector and a reference to data sources. Finally, present energy efficiency levels are discussed. The second part deals with the differentiation of emission reduction objectives, based on differences in energy efficiency. It discusses how CO_2 emissions were calculated and in what way the differentiation of commitments was established. The second part concludes with the resulting differentiation of commitments. The discussion and the conclusions regard both the energy efficiencies and the resulting differentiation of commitments.

The Assessment Of Energy Efficiencies In Heavy Industry

Definitions

Activity, efficiency and structure

Energy consumption in an industrial subsector is determined by three factors. The first is activity or physical production. In general large production figures involve large energy consumption.

Another factor is energy efficiency, which indicates the amount of energy required per unit of human activity. Schipper et al. (1992) regard it as a quality of a system of equipment i.e. technology and operation. Energy efficiency in industry is often expressed as the Specific Energy Consumption (SEC), defined as the energy consumption of an activity divided by the resulting physical production, measured in weight or number of products. It has become clear that physical indicators are more suitable for an adequate assessment of energy efficiency levels than economic indicators (Martin et al. 1994; Phylipsen et al. 1997; Phylipsen et al. 1998a; Worrell et al. 1997).

Finally, energy consumption is affected by the structure of a subsector, indicated by the product mix. The iron and steel sector in one country may for instance produce a larger share of secondary steel (mostly from scrap) than the other and thus demand less energy. Contrary to product mix feedstock and process type are not considered structural indicators, unless they influence the product mix or product quality. For example, the share of scrap input in the process of steel making is considered as a structural indicator, because a higher share decreases steel quality and thus affects the final product.

Energy consumption

Energy consumption data in this study all represent primary energy. They are derived from either net available energy or final energy. Net available energy is the amount of energy that actually becomes available to the user. It includes purchased energy, stock changes and autoproduction of (primary) energy. Final energy is a quantity corrected for part of the in-plant conversions to other energy forms. It is defined as net available energy minus the consumption by in-plant conversion processes plus the production by in-plant conversion processes; i.e. the transformation losses are excluded. Most statistics attribute combined heat and power generation (CHP or cogeneration) to the transformation sector (Phylipsen et al. 1998d) while some also attribute other ways of in-plant power production to the transformation sector. Thus final energy is reported. Although Phylipsen et al. recommend net available energy to compare energy efficiencies, net available energy data may be lacking so that one has to rely on final energy data. As a consequence variations in energy efficiency due to a different share of CHP are not accounted for.

Primary energy data are calculated assuming 33% to 40% conversion efficiency in power generation depending on the subsector. This means that the fuel consumed for electricity is multiplied by a factor of 3.0 to 2.5 and added to the consumption of other fuels to obtain primary energy consumption. All energy consumption data are based on lower heating values.

Reference level

In order to evaluate the energy consumption in a country's industry, a reference value for the specific energy consumption is indispensable. Reference SECs may be based on either

- the best practice observed: the complete production plant with the lowest specific energy consumption that already is in full operation;
- the best practical means: the production plant with the lowest specific energy consumption that can be realized using proven technology at reasonable costs; or
- the best available technology: the production plant with the lowest specific energy consumption that can be realized using proven technology (Phylipsen et al. 1997).

In this paper both best practice observed and best practical means have been used. The technologies representing these are mentioned in Table 1.

Table 1. Technologies representing best practice

Subsector	Technology	Source
Petrochemicals	ABB Lummus Crest SRT-5 coil	(Phylipsen et al. 1998b)
Ammonia	ICI AMV-process	(Worrell 1994)
Iron and steel	1988 integrated steel plant in the Netherlands and an EAF plant in Germany	(Worrell et al. 1997)
Aluminium	Standard Hall-Heroult cell for newly installed capacity	(Phylipsen et al. 1998b)
Cement	Dry process short kiln with a 4-stage preheater (clinker production)	(Worrell et al. 1995)
Pulp and paper	Each of the partial processes based on the current situation in Dutch and Finnish industries and on model values	(Farla et al. 1997)

It must be emphasized here that the reference SEC is a dynamic quantity. New investments decrease reference SECs based on best practice observed and technological innovations decrease reference SECs based on best available technology. However in this study the reference SEC values were kept at a constant level.

Correcting Specific Energy Consumption For Structural Differences

The SEC-values that are used in this study have been corrected for structural differences between countries according to the method described by Phylipsen et al. (1997). To this end actual specific energy consumption figures for each of a subsector's products have been multiplied with the accompanying production data for these products. Thus an overall actual SEC figure for the subsector is obtained. This may be compared with an overall reference SEC value that can be similarly calculated. However in order to obtain an overall reference SEC reference SECs instead of actual SECs are multiplied with the production data for each of the subsectors products.

Structural Indicators And Data Collection

Structural indicators for the various subsectors are discussed in Phylipsen (1998c) and have been summarized in Table 2. In the following the processes in each of the industrial subsectors will be described briefly. More extended descriptions can be found in the refereed literature (below Table 3).

There is a range of processes for the production of *petrochemicals*, each with its own products. As process type is one of the factors influencing product mix, it is considered a structural indicator. In general petrochemicals are produced by steam cracking of hydrocarbon feedstocks. Product mix from steam cracking is determined by the kind of feedstock used and the processing conditions (severity). These may be combined into one structural indicator, namely ethylene yield (Phylipsen et al. 1995).

The most important step in producing *ammonia* is the production of hydrogen, which is followed by the reaction of hydrogen and nitrogen. Hydrogen can be produced by steam reforming of natural gas or by partial oxidation of oil residues. Since the product of both processes is identical, no structural indicators are necessary for ammonia production.

Table 2. Structural indicators [1]

	Structural indicators		Structural indicators
Petrochemical industry	process type ethylene yield (feedstock + severity)	Primary aluminium	-
Ammonia	-	Cement	clinker/cement production ratio
Iron and steel	product mix scrap input	Pulp and paper	paper/pulp production ratio pulping process product type

[1] Phylipsen et al. (1997)

In the *iron and steel* industry, pig iron is produced in the blast furnace. Next, there are basically two routes for the production of steel. The main route for primary steel is production out of pig iron and some scrap in the basic oxygen furnace (BOF). In Eastern Europe, China, India and other developing countries the more obsolete open hearth furnace is still used. Secondary steel is made out of scrap only in the electric arc furnace (EAF). Crude steel is converted into finished products by casting and rolling. The product mix included in this study comprises BOF slabs, EAF slabs, hot rolled products and cold rolled products. The scrap input as a structural indicator is accounted for by including EAF slabs as one of the products. The scrap input in the BOF has not been treated as a structural indicator. Instead a 10% scrap input in the BOF for all countries has been assumed in the calculation of the reference SEC.

Primary aluminium making only covers the electrolytic reduction of alumina to primary aluminium in the so-called Hall-Heroult process. As we study only one process bringing forth only one product no structural indicators are needed.

Two important processes in producing *cement* are clinker and cement production. The major part of the energy is required for clinker production. Burning a mixture of mainly limestone, silicon oxides, aluminium oxides and iron oxides in a kiln produces clinker. The clinker is blended with gypsum and other additives to produce cement. A structural indicator is the ratio of clinker to other additives as this ratio influences product quality and feedstock availability and cannot be chosen freely by the producer. Another structural indicator is the import or export of clinker. Both can be combined into one single structural indicator, namely the clinker to cement production ratio.

In *pulp* production, wood fibres are separated from each other mechanically or chemically, each of the pulping processes having it's own specific energy consumption. In the following *paper* production, the feedstock mixture consisting of pulp or waste paper is dispersed in water. The pulp/water mixture is spread out and water is removed. Important product categories are newsprint, printing paper, sanitary paper, wrapping paper and board. Structural indicators in the pulp and paper subsector are thus the paper/pulp production ratio, the pulping process and the final product type.

Energy Efficiencies

In Table 3 data on the actual specific energy consumption, reference SECs and production data are given. Primary energy levels have been calculated using uniform conversion efficiencies in all countries. This can be justified, as we want to compare subsector energy efficiency and not the efficiency of public electricity production, which accounts for the major part of power consumption in heavy industry.

Table 3. Specific Energy Consumption (SEC, both fuels and electricity), production, and primary energy consumption data for six industrial subsectors. (Data are for various years between 1988 and 1996).

	Specific Energy Consumption	reference	ratio SEC/ reference	production	primary energy[1]	Specific Energy Consumption	reference	ratio SEC/ reference	production	primary energy	Specific Energy Consumption	reference	ratio SEC/ reference	production	primary energy
	Petrochemical industry[2]					Ammonia					Iron & steel[7]				
	GJ/t	GJ/t[3]		Mt	PJ	GJ/t NH_3[4]	GJ/t NH_3[5]		kt[6]	PJ	GJ/t cs[8]	GJ/t cs[9]		Mt cs	PJ
Belgium	34.9	22.4	1.56	1.66	58	37.8	28	1.35	797	30					
Brazil	31.8	22.1	1.44	0.91	29	45.0	28	1.61	1068	48	29,7	18,6	1,60	22,62[12]	671
Finland	33.8	20.9	1.62	0.13	4										
France	33.7	22.7	1.49	2.88	97	37.8	28	1.35	1530	58	24,2	15,0	1,62	18,4	446
Germany	32.9	21.6	1.52	4.16	137	34.1	28	1.22	2576	88	18,3[10]	14,5	1,02	42,2	731
Ireland						38.7	28	1.38	439	17					
Japan	25.1	21.5	117	2.73	69				1576		21,1	15,6	1,35	109,7	2312
Netherlands	32.8	22.3	1.47	2.64	87	34.0	28	1.21	2543	87	20,7	17,1	1,21	5,2	107
Norway	33.8	20.9	1.62	0.20	7										
Poland											28,1	12,0	2,34	10,4	293
Portugal	32.4	23.0	1.41	0.27	9										
South Korea	25.1	21.5	1.17	1.09	27						20,7[11]	15,4	1,34	26,0[13]	539
UK	33.8	20.9	1.62	0.95	32	38.7	28	1.38	1146	44	22,4	14,9	1,51	16,5	370
US	33.9	20.6	1.64	9.95	338	40.1	28	1.43	13125	527	26,6	13,3	2,00	79,7	2121
	Primary aluminium[14]					Cement[17]					Paper & pulp[20]				
	MWh/t[15]	MWh/t[16]		kt	PJ	GJ/t[18]	GJ/t[19]		kt	PJ	GJ/t paper	GJ/t paper[21]		Mt paper	PJ
Belgium						4,15	3,19	1,30	6766	28					
Brazil	16.4	12.8	1.28	931	137	4,47	3,42	1,31	26030	116					
Finland											26.9	23.8	1.13	10.9	294
France	19.0	12.8	1.49	323	55	4,28	3,39	1,26	26827	115	19.0	16.3	1.16	8.6	163
Germany	15.9	12.8	1.24	720	103	3,80	3,52	1,08	27700	105	15.3	14.1	1.08	14.8	226
Ireland						4,84	3,85	1,26	1869	9					
Japan											21.2	17.8	1.19	29.7	630
Netherlands	14.5	12.8	1.14	258	34	2,07	1,98	1,05	3479	7	15.6	12.7	1.23	3.0	47
Norway	16.8	12.8	1.31	871	131										
Poland						6,14	3,51	1,75	12482	77	32.0	24.2	1.32	1.2	38
Portugal						3,99	3,72	1,07	6743	27					
South Korea											14.4	12.2	1.18	6.9	99
UK	16.2	12.8	1.27	276	40	5,19	3,90	1,33	15764	82					
US	16.4	12.8	1.28	4121	609	5,65	3,84	1,47	69734	394	41.7	22.6	1.84	81.0	3379

The data include both fuels and electricity. The ratio between actual national specific energy consumption and the reference SEC is an indication of the energy efficiency. The lower this figure, the more efficient the sector is.

Large differences between actual SEC and reference SEC exist in the petrochemical and iron and steel industries (SEC/reference ratios on average are 1.48 and 1.56 respectively). These differences are somewhat smaller in the ammonia, primary aluminium, cement and pulp and paper industries (1.37, 1.29, 1.29 and 1.27). The largest range in energy efficiency can be found in the iron and steel industry.

Furthermore it can be derived from the table that large efficiency improvements can be achieved in Poland and the United States. The average ratio of actual SEC over reference SEC is 1.80 (over three subsectors) and 1.61 (six subsectors) for these countries respectively. The Germany, Netherlands, South Korea, Japan and Portugal have the lowest ratios, ranging from 1.19 to 1.24. The other countries take an intermediate position, their ratios ranging from 1.32 to 1.46. Of course, energy costs are an important explanation of the observed differences in energy consumption. In general the goal of a firm is not to minimize energy use or carbon emissions.

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[1] For the estimation of primary energy use most refereed authors assumed 40% conversion efficiency for the electricity consumed. For cement Worrell et al. (1995) used 38% conversion efficiency, for the ammonia industry Phylipsen et al. (1998b) used 34% and for iron and steel Worrell et al (1997) used 33%.

[2] Figures represent net available energy i.e. minus exported steam and electricity and regard ethylene production only. All figures regard 1995 and were taken from Phylipsen et al. (1998b)who give regional data only. Actual SEC and reference SEC values were assumed to equal the region's value. If a country covered more than one region, actual SEC and reference SEC were averaged. The production within a region has been divided proportionally according to ethylene production capacities that were taken from Anonymous (1997). The regions comprise 1. The Netherlands, 2. Belgium and Northern France, 3. Mediterranean Europe, 4. UK and Scandinavia, 5. Northwest Germany, 6. other Germany and Austria, 7. USA-Houston area, 8. USA-other Texas, 9. USA-Louisiana, 10. Japan and Korea, 11. South America.

[3] Best practice observed. Phylipsen et al. (1998c) describe how various structural parameters in the petrochemical industry may be combined into one structural indicator, namely ethylene yield, from which the overall SEC can be calculated according to a linear relationship. Phylipsen et al. give indices for the ratio between actual SEC and reference SEC from which we derived reference SEC values.

[4] Net available energy i.e. minus exported steam and electricity and purge gas. From Phylipsen et al (1998b) who give regional data only. Actual SEC and reference SEC values were assumed to equal the region's value. If a country covered more than one region, actual SEC and reference SEC were averaged. The regions comprise 1. The Netherlands, 2. Belgium, France and Italy, 3. Germany and Austria, 4. UK and Ireland, 5. USA-North Central, 6. USA-South Central, 7. USA-South East, 8. Canada, 9. Australia, 10. Caribbean, 11. South America, 12. Indonesia, 13. South Asia, 14. Persian Gulf. Actual SEC-values are based on the best efficient period (usually 31 days) during the 1994-1996 operating period.

[5] Estimated by Worrell (1994)

[6] Production data were set at 80% of their production capacity. Capacity data are for 1995-1996 and were taken from the IFDC (1998).

[7] Figures represent final energy consumption in 1991. Values for actual SECs and the reference SECs are depicted in Worrell et al. (1997). The accompanying data were recalculated using reference SECs from the article and production and energy consumption data from the authors' spreadsheet for each of the following products: slab from the basic oxygen furnace, slab from the electric arc furnace, hot rolled products and cold rolled products. Reference SEC values represent the best practice observed. Production figures are for 1992.

[8] Crude steel

[9] Best practice observed

[10] German iron and steel data regard the former FRG only. Jochem (1992) justifies this assumption, as he gives similar actual SEC data for pig iron production in f-FRG and f-GDR (13,0 and 13,1 GJ/t resp.). In addition, they report an overall energy consumption for pig iron in f-GDR that amounts to only 9% of f-FRG energy use in pig iron (37 and 426 PJ resp.).

[11] Sinton (1996)

[12] IBS (1997)

[13] IISI (1997)

[14] Figures regards the conversion of alumina into aluminium (the Hall-Heroult process) only and represent final energy.

[15] Actual SEC-values are depicted in (Phylipsen et al. 1998b) and were taken from the authors' spreadsheet. For France data are from 1987, for the US from 1991, for the UK this is unknown and for others they are from 1990. UK data are from (ETSU 1996).

[16] Best practice observed, based on Eichhammer (1992). This value does not comprise anode manufacture, although Phylipsen et al. (1998c) recommend the inclusion of anode production.

[17] Figures represent final energy consumption. All data are from Worrell et al (1995) and regard 1988.

[18] More recent (1994) actual SEC figures are: Brazil 4.1, France 4.1, Germany 3.8, Poland 5.6 and US 5.5 GJ/t (Hendriks et al. 1999 (forthcoming)).

[19] Best practice observed

[20] All data from (Phylipsen et al. 1998b). Actual SEC and reference SEC are valid for 1993; production data are for 1995. For the pulp and paper industry it is not always clear whether data represent net available or final energy. For the Netherlands final energy is given for sure. It is likely that for most other countries final energy consumption figures are used as well, in accordance with the approach followed by the International Energy Agency, but the German data probably represent net available energy (Phylipsen et al. 1998b). This uncertainty is especially difficult because in general CHP in the pulp and paper industry is substantial. Another problem is that for the Netherlands the paper and board converting industry is included, whereas it is not for South Korea. For other countries this is unknown. These issues on system boundaries cause a lack of clarity on the comparability of actual SEC and reference SEC.

[21] Best practice observed

Establishing a Differentiation of commitments

Now that we have determined the differences in energy efficiency for a range of countries for at least a few sectors, we can take the next step: establish the effect of energy efficiency differences on a differentiation of GHG emission reductions. In Table 4 the countries and subsectors that were sufficiently documented are summed up.

In the following we assume that for one specific year in the future, say 2015, we have to design a burden differentiation based on a sector approach. Heavy industry is one of these 'sectors'. In this paper we *only* calculate a *partial* allowance for the heavy industry on a country-by-country basis. If comparable guidelines were elaborated for all other sectors as well, they could be counted together to a total GHG emission allowance for each of the countries.

Table 4. Countries and industrial subsectors included

country	sectors	petrochemicals	ammonia	iron & steel	primary aluminium	cement	pulp & paper
Belgium	3	●	●			●	
Brazil	5	●	●	●	●	●	
Finland	2	●					●
France	6	●	●	●	●	●	●
Germany	6	●	●	●	●	●	●
Ireland	2		●			●	
Japan	3	●		●			●
Netherlands	5	●	●	●	●	●	●
Norway	2	●			●		
Poland	3			●		●	●
Portugal	2	●				●	
South Korea	3	●		●			●
United Kingdom	5	●	●	●	●	●	
United States	6	●	●	●	●	●	●

CO_2 Emission Factors

In order to establish a differentiation of commitments one has to consider not only energy efficiencies but also fuel mix, as this varies across countries and subsectors. CO_2 emission factors for the various subsectors (fuel only) and for power production for various years around 1990[1] are given in Table 5. In the calculations for each country one integrated emission factor was used for each subsector, determined as a weighted average from the fuel emission factor in that subsector and the electricity emission factor in the country concerned. Weights were based on the shares of fuels and electricity in final energy consumption in the subsector involved.

The table shows that CO_2 emissions in electricity production vary widely. Brazil has an 89% share of hydropower, whereas France generates a similar share in nuclear power plants. Finland has a combined 55% share of nuclear energy and hydropower. Japan has a 60% share of fossil fuels in the input fuel mix for power generation. Both the United Kingdom and the United States have high shares of coal input as well (65% and 53% respectively). The low CO_2 factor for the Irish petrochemical industry must be attributed to its 78% share of gas.

If data availability allowed so, emissions from subsectors were based on actual SEC values, production figures and the CO_2 emission factors. If no data on production and energy

[1] The exact year for the emission factors in a certain subsector was determined by the year from which the SEC data were derived for that particular sector.

consumption were available another approach was needed. If no data for the petrochemical industry were available, we took emission factors for the entire chemical industry.

Likewise, we derived ammonia emission figures for non documented sectors from the entire chemical industry, cement emissions from the entire non-metallic minerals industry, and pulp and paper emissions from the entire paper, pulp and printing subsectors. We estimated the primary aluminium emissions at 75% of the non-ferrous industry for non-documented sectors. This share has been based on Worrell (1994), who indicated primary energy demand for several subsectors in the non-ferrous industry in the European Union. For the iron and steel industry emissions no adjustments were made to the IEA emission figure.

Table 5. CO_2 emission factors [kt CO_2/PJ] for industrial subsectors and electricity generation [1]

	petrochemicals, ammonia[2]	iron & steel[3]	cement[4]	paper & pulp[5]	electricity[6]
Belgium	67	88	76	70	59
Brazil	72	91	83	75	8
Finland	74	86	85	58	39
France	71	89	71	65	16
Germany	70	85	75	70	119
Ireland	59	81	75	75	204
Japan	75	91	86	76	103
Netherlands	66	89	63	56	182
Norway	77	94	85	76	0,1
Poland	74	86	86	89	303
Portugal	75	89	86	75	145
South Korea	75	92	89	75	94
Spain	72	88	79	64	114
United Kingdom	70	86	74	74	191
United States	77	94	94	94	165

[1] Figures are based on IEA (1997a; 1997b). The presented emission factors for the industrial subsectors include fossil fuels only. In the calculations emissions from both heat and electricity were included. Emissions from heat were based on the 1990 fossil fuel mixes in each of the subsectors. The IEA reports heat consumption in all subsectors in Poland (except primary aluminium) and in the German and US chemical industries. Primary aluminium was assumed to lean entirely on power consumption.

[2] 1995; based on entire chemical industry

[3] 1991

[4] 1988; based on entire non-metallic minerals industry

[5] 1993; based on the entire pulp, paper and printing sector

[6] 1990; derived from fuel mix for public electricity, except for the Netherlands and Poland. For these countries the IEA reports the fuel mixes for public power generation under the heading public CHP. Fuel consumption has been allocated on an exergy bases (Phylipsen et al. 1998c). The quality factor for heat has been set at 0.2.

Table 6 shows CO_2 emissions per kg product for each of the six industrial subsectors. Although these figures may seem to illustrate well which countries are large and which are small emitters, they are not corrected for structure. In addition, they reflect fuel mix and type of electricity generation, which is outside the scope of this paper on industrial energy efficiencies. In order to judge energy efficiencies, the ratio of actual SEC over reference SEC in Table 3 is a better criterion. Note that for this ratio, the CO_2 intensity of the energy consumed is irrelevant, as it has been divided out

Table 6. CO_2 emissions per kg product[1] in six subsectors of heavy industry

	Petrochemicals	Ammonia	Iron & Steel	Primary aluminium	Cement	Pulp & paper
	kg CO2/ kg ethylene	kg CO2/ kg NH_3	kg CO2/ kg cs [1]	kg CO2/ kg Al	kg CO2/ kg cement	kg CO2/ kg paper
Belgium	2,3	2,5			0,31	
Brazil	2,1	2,9	2,3	1	0,29	
Finland	1,5					0,8
France	2,2	2,4	1,9	3	0,27	0,9
Germany	2,6	2,7	1,6	17	0,30	1,4
Ireland		2,8			0,57	
Japan	2,0		2,0			1,4
Netherlands	2,5	2,6	2,0	24	0,16	1,6
Norway	1,9			0		
Poland			3,0		0,61	4,8
Portugal	2,6				0,27	
South Korea	1,9		1,9			1,2
United Kingdom	2,8	3,3	2,1	28	0,44	
United States	3,4	4,0	2,9	24	0,60	5,1

[1] crude steel

Approach For Establishing A Differentiation Of Commitments

The CO_2 emissions allowance for the sector 'heavy industry' is calculated taking into account volume growth and energy efficiency into account as follows:

Volume growth: In all calculations we accounted for a growth in emissions. We assumed a moderate annual 1% growth in physical production in heavy industry over the next 25 years for all countries except Brazil. For Brazil we assumed a 2% growth rate in order to meet its need for further development. Note that the growth rate in physical production in heavy industry does not equal the economic growth rate. In general physical growth in heavy industry is smaller than growth (in monetary terms) in other branches of the economy.

Energy efficiency: First we determined a target-SEC for each sector. As a base case we chose a level of 80% of the best practice level in the early 1990s. Subsequently we assumed that each sector in each country should bridge a fixed fraction of the difference between the actual SEC in the early 1990s and the target SEC.

In the formula both effects are taken into account as follows:

$$A_{20xx} = E_{1990} * (1+p)_{20xx-1990} \frac{SEC_{1990} - f * (SEC_{1990} - SEC_{target})}{SEC_{1990}} \quad (1)$$

in which:

A_{20xx} = the CO_2 allowance for heavy industry for a year in the future
E = CO_2 emission in 1990
p = annual increase of the production in heavy industry (in physical terms)
SEC_{1990} = actual specific energy consumption in 1990
SEC_{target} = target for the specific energy consumption to be reached at some time in the future
f = fraction of the difference between the actual 1990 SEC and the target SEC that has to be bridged towards 20xx

The fraction f is adjusted so that the total CO_2 emissions from heavy industry in the year 20xx reach a certain pre-set level. In the further calculations in this paper we determine f in such a way that the partial CO_2 emission allowances for heavy industry are 5% from those in 1990.

Resulting Differentiation Of Commitments

The CO_2 emission reduction objectives for heavy industry in the year 2015 that can be derived from industrial energy efficiencies are given in Table 7. The first column shows the reduction objectives if a flat rate reduction is applied. In this case all countries reduce their 1990 emissions by 5% at an annual 1% physical production growth. However, since we assumed a 2% growth for Brazil, its 5% reduction is outweighed by its higher growth.

The second column shows reduction objectives based on national heavy industry efficiency improvements to a target SEC equal to 80% of the reference level. A 55% share of the difference between the actual SEC in 1990 and the target SEC (the factor f in formula (1)) was needed to achieve an overall 5% reduction among the countries considered. Now some countries reduce their emissions, whereas for others their reduction efforts are outweighed by their economic growth so that on balance their emissions may increase. Poland and the US have the highest partial reduction targets (-15% and –10%). Norway, France, the United Kingdom and Belgium should also reduce their emissions (–8% to –3%). Brazil would belong to this same group if it had not been assigned a higher growth rate. Ireland, Japan and South Korea should stabilize their emissions at 1990 levels. Germany, the Netherlands, Finland and Portugal are allowed to grow (3% to 7%).

The third column gives reduction objectives based on national heavy industry efficiency improvement to 100% of the reference level instead of 80% of the reference. In this case, a 76% share of the difference between the actual SEC in 1990 and the target SEC was needed to reach an overall 5% reduction. The differences between the objectives in the previous case therefore become even more pronounced.

Table 7. Flat rate differentiation of commitments and differentiations based on target SECs equal to 80% and 100% of the reference SEC respectively.

	Percent reduction in 1990 CO_2 emissions from heavy industry required by 2015		
	flat rate [%]	target SEC equal to 80% reference [%]	target SEC equal to 100% reference [%]
Belgium	-5	-3	-1
Brazil	+7 [1]	20	20
Finland	-5	7	16
France	-5	-4	-3
Germany	-5	3	10
Ireland	-5	0	4
Japan	-5	0	4
Netherlands	-5	3	9
Norway	-5	-8	-9
Poland	-5	-15	-21
Portugal	-5	7	16
South Korea	-5	0	5
United Kingdom	-5	-4	-2
United States	-5	-10	-13

1 Contrary to the all others Brazil was allowed a 2% production volume growth.
2 –5% if the volume growth rate is set at 1%.
3 –5% if the volume growth rate is set at 1%.

Discussion

Data

For a discussion o the data we refer to the sources and to Phylipsen et al. (1997). Special care should be taken in interpreting energy consumption data in pulp and paper industry (Farla et al. 1997; Phylipsen et al. 1998c).

The collection of similar data for a wide range of countries appears a major obstacle when establishing a worldwide differentiation of reduction objectives. Such an effort has been initiated though by the INEDIS (International Network for Energy Demand analysis in the Industrial Sector) Network, led by Lawrence Berkeley National Laboratory in co-operation with Utrecht University.

For the various countries data on different sets of subsectors were available. The energy efficiency in these subsectors was extrapolated to the non-documented subsectors. This method may yield somewhat misleading results as a documented sector with an especially high or low energy efficiency covers a large part of the emissions from the documented subsectors in a country. In order to test this, we used IEA data for the non-documented subsectors and made the room for energy efficiency improvement equal to first the country average and next the subsector average. For most countries the resulting objectives did not differ more than 1% from the initial differentiation based on an incomplete data set. It turned out that only for Finland, Norway and Portugal the resulting objectives differ markedly from the initial differentiation. This is caused by the fact that the documented sectors in these countries can reduce emissions in their documented sectors to a much larger or a much smaller extent than the country or subsector average.

Fuel mix and emission factors

It must be noted that potential CO_2 emissions reductions due to changes in fuel mix have not been considered. Although a shift in fuel mix does not contribute to energy efficiency improvement, it does influence CO_2 emissions and hence the differentiation of commitments calculated.

Differences in fuel mixes between countries and subsectors were taken into account in the calculations on the differentiation of commitments. However the impact of fuel mix on the differentiation appeared remarkably small. When one single fuel mix was used for all countries and subsectors partial reduction objectives change 0.2 to 0.3% for some countries (e.g. the Netherlands, South Korea, the United Kingdom and the United States), whereas for other countries there was no noticeable effect.

CO_2 emission factors were calculated using IEA statistics. It would be preferable to calculate these for ammonia and the petrochemical industry separately instead of combining these into one figure based on the chemical industry as a whole, but this is not considered a major problem.

The role of innovation

In this study the role of innovation has been largely underexposed for several reasons. First, it is extremely difficult to assess in what way and to what extent innovation will contribute to the mitigation of climate change in each of the countries included. Therefore, we accounted for a target SEC level equal to 80% of the current reference SEC for all countries and did not differentiate the penetration degree of innovation further. We assumed that current energy efficiency levels are sufficiently indicative for the emission reduction that can possibly be attained.

In addition, in most cases the reduction of CO_2 emissions will not be the primary reason for innovation. Costs savings, the shift to new raw materials that are more easily at hand or to a more convenient production process are the chief motives for investing in innovative technologies. Accompanying energy savings are most often a side effect that cannot constitute a firm basis on which to base partial CO_2 emissions allowances for heavy industry.

Conclusions

Energy efficiencies in heavy industry differ strongly from country to country. In this paper we have compared actual energy efficiencies in the late 1980s and early 1990s to a reference level, based on best-practice. We found that countries with less energy-intensive industries on average have specific energy consumption 1.2 times this level whereas for other countries factors from 1.5 to 1.7 occur. Note that data availability is still limited.

We used the data for establishing a partial emission allowance for a future burden differentiation in the framework of the Climate Treaty. The guidelines we designed take into account both a reasonable volume growth and differences in energy efficiencies. Taking into account energy efficiency differences leads to a difference in partial allowances of 35% within the group of countries considered. Since heavy industry typically accounts for 20% to 30% of GHG emissions, this means that the effect of these differences in total allowances is 7% to 10%.

Although the values of this exercise are preliminary – due to limited data availability – we demonstrate that it makes sense to account for differences in industrial energy efficiencies in future burden differentiation rules.

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