PRELIMINARY OPTIONS FOR METHODOLOGIES TO APPLY ADJUSTMENTS UNDER ARTICLE 5.2 OF THE KYOTO PROTOCOL

Industrial processes

Expert report

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I. Introduction

A. General

Greenhouse gas emissions are produced from a variety of industrial activities which are not related to energy. The main emission sources are industrial production processes which chemically or physically transform materials. During these processes, many different greenhouse gases, including CO_2 , CH_4 , N_2O, HFCs and PFCs, can be released. Cement production is a notable example of an industrial process that releases a significant amount of CO_2. Different halocarbons (and SF_6) are also consumed or produced in industrial processes or used as alternatives to ozone depleting substances (ODS) in various applications. Table 2-1 gives an overview of potential industrial emission sources of GHGs and ozone and aerosol precursors (NO_x , NMVOCs, CO and SO_2).

Table I-1: Potential emissions from industrial processes (from Revised 1996 IPCC Guidelines).

Process	Greenhouse Gases						Ozone and Aerosol Precursors			
	CO_2	CH_4	N_2O	PFC	SF_6	HFC	NO_x	NMVOC	CO	SO_2
Mineral Products										
Cement production	**x**									x
Lime production	**x**									x
Limestone use	**x**									
Soda Ash prod. And use	**x**									
Asphaltroofing								x	x	
Road paving							x	x	x	x
Other	**x**	**x**					x	x	x	x
Chemical industry										
Ammonia	**x**						x	x	x	x
Nitric acid			**x**				x			
Adipic acid			**x**				x	x	x	
Urea			**x**							
Carbides	**x**	**x**						x	x	x
Caprolactam			**x**							
Petrochemicals		**x**	**x**			x		x		x
Metal Production										
Iron, steel and ferroalloys	**x**	**x**					x	x	x	x
Aluminium	**x**	**x**		x	x		x	x	x	x
Magnesium	**x**				x		x	x	x	x
Other metals	**x**	**x**			x		x	x	x	x
Other										
Pulp and paper							x	x	x	x
Food and drink production								x		
Production of halocarbons				x	x	x				
Use of halocarbons and SF6				x	x	x				
Other sources	**x**	**x**	**x**	x	x	x	x	x	x	x

The table does not necessarily cover all potential GHGs or industrial sources.

B. Pitfalls

1. Double Counting

The IPCC Methodology for national GHG inventories requires an intentional double reporting of NMVOCs, methane and carbon monoxide, firstly in their individual inventories, and as CO_2 equivalent in the national CO_2 inventory. Whether an explicit addition to the CO_2 inventory is required depends on how the national CO_2 inventory has been calculated.

2. Combustion vs. Process emissions

In some instances industrial process emissions are produced in combination with fuel combustion emissions and it may be difficult to decide whether a particular emission should be reported within the energy or industrial processes sector. Where the main purpose of the fuel combustion is to use the heat released, the resulting emissions are included as energy emissions, not industrial process emissions. There are, however, some chemical processes or stages of processes, which oxidise carbon as a feedstock and are exothermic. The reduction of iron in a blast furnace through the combustion of coke is an example. Invariably the heat released is used within the processes or for other energy needs of the producer. However, in this case, since the primary purpose of coke oxidisation is to produce pig iron, the emissions are considered to be industrial.

II. Overview of methods considered

A. IPCC Tier 1 methods

1. Description of method

This method simply applies the Tier 1 methods from the Revised 1996 IPCC Guidelines, referred to below as IPCC Guidelines, using the basic formula:

$$EMISSION_{i,j} = A_j \times Ef_{i,j},$$

where	$EMISSION_{i,j}$	the emission of gas i from sector j
	A_j	the intensity of the production process in sector j (activity rate)
	$Ef_{i,j}$	emission factor: an assumed proportionality constant between the activity rate in sector j and the emission of gas i.

The Tier 1 method provides suggestions for the activity data and for the emission factors to be used, for all industrial sectors that are expected to be relevant.

The IPCC Guidelines propose country averaged methods, with in some cases assumptions of the technologies applied within an industrial sector. Within this adjustment process, it is recommended to stick to this country average methods, unless more detailed information is included in the national communication.

2. Technical preconditions and data requirements

To apply the Tier 1 method, data on industrial activities in the relevant sectors are needed. The emission factors can be obtained from the IPCC Guidelines.

B. Estimation based on Annex B average emission rates and country specific driving factor

1. Description of method

This method relies on similarities between Annex B countries. It assumes that implicit relations between some driving factor and the emissions of greenhouse gases is similar for all Annex B countries. This approach applies therefore a similar equation as the one given above:

$$EMISSION_{i,j} = DF \times ER_{i,j},$$

where	$EMISSION_{i,j}$	refers to the emission of gas i from sector j
	DF	to the intensity of a specific driving factor for the country
	$ER_{i,j}$	emission rate: an Annex B countries' averaged proportionality constant between the driving factor and the emission of gas i.

The driving factor in this method might basically be more distant from the actual process than the one used in the IPCC Tier 1 method. Candidates for such driving forces could be
- the economic output (in monetary or physical units)
- the energy input (obtained from energy statistics or energy balances)
- the labour input (from national statistics)

in specific or even more or less aggregated industrial sectors.

The proportionality constants here are called "emission rates" since no relation with technology is made and no measured data underpin the proportionality. It simply results from such assumptions as:

- all Annex B countries have similar prices for similar products
- the processes in the industry in these countries are using similar energy resources and
- these processes require similar labour input.

2. Technical preconditions and data requirements

The method requires that for enough Annex B countries emission data and appropriate data on driving factors are available to perform the calculations.

C. Extrapolation based on a driving factor

1. Description of method

This method assumes that technological and economical changes in a country do not occur rapidly as compared to the successive emission reports by the country. The method is mathematically equivalent to the one described above "Estimation based on Annex I averages and driving factor", the difference being that historic country-specific data are used:

$$EMISSION_{t,i,j} = DF_t \times ER_{t-x,i,j},$$

where
$EMISSION_{t,i,j}$ refers to the emission of gas i from sector j in year t
DF_t the intensity of a specific driving factor for the country in year t
$ER_{t-x,i,j}$ emission rate: an proportionality constant between the driving factor and the emission of gas i from the most recent past year (year t - x).

This can also be written down as follows (also assuming a constant emission rate):

$$EMISSION_{t,i,j} = EMISSION_{t-x,i,j} \times INDEX_t$$
$$INDEX_t = DF_t/DF_{t-x},$$

where
$EMISSION_{t,i,j}$ refers to the emission of gas i from sector j in year t
$EMISSION_{t-x,i,j}$ refers to the emission of gas i from sector j in a past year t - x
$INDEX_t$ index number: ratio between the driving factor in year t and the driving factor in a past year t-x
DF_t the intensity of a specific driving factor for the country in a past year (year t - x).
DF_{t-x} the intensity of a specific driving factor for the country in a past year (year t - x).

For this method the emission rate with respect to the driving factor is assumed to be constant. The emission rate will only change over time, if the technology applied within the sector and in the country changes. This might occur when a shift from older technologies towards more modern ones occurs over time. Depending on the driving factor used and the level of aggregation, changes in driving factors can also be caused by shifts in the contribution to the aggregated sector driving factor, for instance sector output in monetary units.

Assuming non-constant emission rates, emission rates can also be calculated from available time series on emissions and relevant driving factors. The emission rates for the inventory year can then be estimated by extrapolation from the emission rate time series. A precondition to the last option is that the intensity of the driving factor for the inventory year should be available either from industrial production statistics, otherwise the driving factor should be estimated using extrapolation techniques.

When the emissions of a year within a time series in not available, the emissions can be assessed by interpolation. The interpolation can be based on available driving factors for the missing year and using interpolated emission rates or the interpolation can be applied directly to the emissions in the available years, see method E:

$$ER_t = (year_t - year_{t-x}) \times \frac{ER_{t+y} - ER_{t-x}}{year_{t+y} - year_{t-x}} + ER_{t-x}$$

The emission rates will change over time, if the technology applied within the sector and the country changes. Emission rates will also change due to introduction of emission abatement technologies. Using driving factors more distant from the actual process, like economic production rates or energy input, introduces other uncertainties. The information on economic production rates or energy input is usually presented in more aggregated figures, on the level of for instance total industrial value added. Therefore structural changes within the sector causes the emission rates to change.

2. Technical preconditions and data requirements

This method assumes a constant ratio between a driving factor and the emission rate. To use such a driver to estimate emissions, one should actually first prove a linear relation between the emissions and the driving factor, i.e., if the driver goes up, do the emissions go up or the other way around. Figure III-1 (in section III C) shows the relationship between the driver “industrial value added” and the carbon dioxide emissions from the cement industry. The figures show that the linear relation holds for all countries for the period since 1994. For earlier years deviations from this behaviour are obvious.

This method will only be applied when more specific activity data are not available. As stated above, it is assumed that changes in the economic (industrial) structure of a country and in the technology applied within an industrial sector, do not take place rapidly. In selecting the time period, on which the extrapolation will be based, this should be kept in mind.

This method assumes that time series of both the driving factor data and emission data are available.

The changes in emission rates over time can be extrapolated using a function, fitted to the historical data. To this end the functionality of a modern spreadsheet programme like Microsoft Excel, which allows different extrapolation models by using the “trend line” facilities, can be used.

D. Linkages of emissions between sources and gases

1. Description of method

This method might be applied apply whenever more then one gas is emitted from a certain source, but not all gases are reported in the national emission tables.

$$EMISSION_{i,j} = EMISSION_{k,j} \times EQ_{i\text{-}k,j}$$
$$EQ_{i\text{-}k,j} = Ef_{i,i}/Ef_{k,j},$$

where:

$EMISSION_{i,j}$	the emission of gas i from sector j
$EMISSION_{k,j}$	the emission of gas k from sector j
$EQ_{i\text{-}k,j}$	Emission (factor) quotient of i to k
$Ef_{i,i}$	an assumed proportionality constant between the activity rate in sector j and the emission of gas i
$Ef_{i,k}$	an assumed proportionality constant between the activity rate in sector j and the emission of gas k

This method seems straight forward, but this might not apply to the relation between the emitted substances. There is a wide range of factors disturbing the straight forwardness, like technologies and emission reduction measures applied within a industrial sector and the fuel quality. For instance the sulphur content of coal strongly depends on the region where the coal comes from while the heat content of the various types of coal might be equal. This results in complete different emission ratios of SO_2-CO_2. On the other hand, the relation between the emissions of other substances within a industrial sector can be quite explicit. The emissions of NO_x, N_2O and NMVOC are related through applied technology and emission reduction measures. For instance, through the application of selective catalytic reduction which converts NO_x to N_2O, NO_x emissions are inversely related to N_2O emissions.

2. Technical preconditions and data requirements

The method can only be applied in the case that emissions of two gases are correlated. The ratios can either be based on the default IPCC emission factors or can be derived from reported country specific emissions as country averaged emission ratios.

Table II-1: Emission factor quotients based on emissions factors from the Revised 1996 IPCC guidelines.

	Emission quotients	
	SO_2/CO_2 (kg/kg)	NO_x/CO_2 (kg/kg)
Cement	6.02E-04	
Ammonia	1.94E-05	
Aluminium	9.15E-03	1.30E-03

E. Interpolation and extrapolation

1. Description of method

When the intensity of the driving factor, the emission factor or the emission for the inventory year is not (yet) available, the driving factor, the emission factor and the emissions can be estimated by extrapolation from the available time series.

When the emissions of year within a time series is not available, the emissions can be assessed by interpolation. The interpolation can be based on available driving factors for the missing year or the interpolation can be applied directly to the emissions in the available years:

$$EMISSION_t = (year_t - year_{t-x}) \times \frac{EMISSION_{t+y} - EMISSION_{t-x}}{year_{t+y} - year_{t-x}} + EMISSION_{t-x}$$

2. Technical preconditions and data requirements

This method assumes that time series of data on either the driving factor or emission data are available.

The changes in emission rates over time can be extrapolated using a function, fitted to the historical data. To this end the functionality of a modern spreadsheet programme like Microsoft Excel, which allows different extrapolation models by using the “trend line” facilities, can be used, see also method C.

III. Working out the methods to obtain revised estimates

A. IPCC Tier 1 methods

This method calculates the emissions from industrial activities according to the standard IPCC method, following the IPCC Guidelines. The recommended emission factors should be used. If the emission factors are reported as ranges, averaged values should be used.

World wide industrial production data can be obtained from the United Nations Industrial commodity statistics. The Industrial commodity statistics yearbook provides statistics in physical quantities of about 530 industrial commodities by country including data for a ten year period. Data are also available on diskettes and magnetic tape covering the years 1970-1995. (UN, 1996)

The United States Geological Survey (USGS) provides information on world wide production supply and demand on 140 minerals and materials, essentially to the United States. http://minerals.usgs.gov/minerals/pubs/commodity/

SRI International's Chemical Economics Handbook provides evaluation of detailed end-use demand patterns, analysis of production and consumption trends and projections of future supply/demand for over 400 chemical products and product groups. Other report features include discussions of producers and plant capacities, manufacturing technologies, cost/price factors, and international trade. Historical time series are included for most data portions of the reports. Geographic coverage emphasises United States, Western Europe, and Japan. A limited amount of information on other regions is included in many reports. http://ceh.sric.sri.com/

The numbers here are derived from the data as available at the USGS.

Table III-1: Reported production rates from the United States Geological Survey.

Production (kton)	*Production rates USGS*							
	1990	1991	1992	1993	1994	1995	1996	1997
Time since base year (1990)	0	1	2	3	4	5	6	7
Cement								
France	26400	26507	21165	20464	21296	19692	18340	19000
Hungary	3930	2529	2236	2533	2813	2875	2776	2800
New Zealand	750	576	579	800	900	950	974	976
United Kingdom	14700	12297	11006	11093	12307	11805	12214	12900
United States of America	71400	68465	70883	75117	79353	78320	80818	84255
Ammonia								
France	1590	1604	1848	1871	1480	1470	1570	1757
Hungary	443	261	152	237	302	307	347	339
New Zealand	70	70	68	78	81	79	68	80
United Kingdom	1150	1011	869	873	1006	799	850	642
United States of America	12700	12800	13400	12600	13300	13000	13400	13300
Aluminium								
France	326	286	418	426	438	372	380	399
Hungary	75	63	27	28	31	25	30	35
New Zealand	260	258	243	277	269	273	285	310
United Kingdom	294	294	244	239	231	238	240	248
United States of America	4050	4121	4042	3695	3299	3375	3577	3603

Reported party emission data and default IPCC emission estimates using external production data from the USGS are presented below for the production of cement and the production of ammonia and aluminium in the years 1996 and 1997.

Table III-2: Estimated and reported carbon dioxide emissions (Gg), using activity data from the USGS and default emission factors(above) and Annex B averaged emission factors (middle) and country averaged emission factors (below). The “error” indicates the deviation of the obtained estimates from the values reported by parties.

CO_2 Emissions (Gg)	*IPCC default emission factors*							
	1996				1997			
	Estimate	emission factor (kg/kg)	Reported	"error"	Estimate	emission factor (kg/kg)	Reported	"error"
Cement								
France	9816	0.4985	8042	**22%**	9142	0.4985		
Hungary	1433	0.4985	1374	**4%**	1384	0.4985		
New Zealand	474	0.4985	503	**-6%**	486	0.4985	503	**-3%**
United Kingdom	5885	0.4985	5887	**0%**	6089	0.4985	6157	**-1%**
United States of America	39043	0.4985	37061	**5%**	40288	0.4985		
Ammonia								
France	2279	1.55	2443	**-7%**	2434	1.55		
Hungary	476	1.55			538	1.55		
New Zealand	122	1.55			105	1.55		
United Kingdom	1238	1.55	1379	**-10%**	1318	1.55	814	**62%**
United States of America	20150	1.55	24171	**-17%**	20770	1.55		
Aluminium								
France	614	1.65	467	**31%**	627	1.65		
Hungary	41	1.65	174	**-76%**	50	1.65		
New Zealand	450	1.65	493	**-9%**	470	1.65	504	**-7%**
United Kingdom	393	1.65	372	**6%**	396	1.65	384	**3%**
United States of America	5569	1.65	5258	**6%**	5902	1.65		

CO2 Emissions (Gg)	*Annex B averaged emission factors*							
	1996				1997			
averages based on	1990-1995				1990-1996			
Cement	Estimate	emission factor	Reported	"error"	Estimate	emission factor	Reported	"error"
France	9398	0.477	8042	**17%**	8755	0.477		
Hungary	1372	0.477	1374	**0%**	1325	0.477		
New Zealand	453	0.477	503	**-10%**	465	0.477	503	**-8%**
United Kingdom	5634	0.477	5887	**-4%**	5831	0.477	6157	**-5%**
United States of America	37380	0.477	37061	**1%**	38582	0.477		
Ammonia								
France	2324	1.581	2443	**-5%**	2500	1.592		
Hungary	485	1.581			553	1.592		
New Zealand	125	1.581			108	1.592		
United Kingdom	1263	1.581	1379	**-8%**	1353	1.592	814	**66%**
United States of America	20552	1.581	24171	**-15%**	21337	1.592		
Aluminium								
France	568	1.528	467	**22%**	630	1.657		
Hungary	38	1.528	174	**-78%**	50	1.657		
New Zealand	417	1.528	493	**-15%**	472	1.657	504	**-6%**
United Kingdom	364	1.528	372	**-2%**	398	1.657	384	**4%**
United States of America	5157	1.528	5258	**-2%**	5928	1.657		

CO2 Emissions (Gg)	*Country averaged emission factors*							
	1996				1997			
Average based on	1990-1995				1990-1996			
Cement	Estimate	emission factor	Reported	"error"	Estimate	emission factor	Reported	"error"
France	7879	0.400	8042	**-2%**	7438	0.406		
Hungary	1435	0.499	1374	**5%**	1384	0.499		
New Zealand	543	0.572	503	**8%**	543	0.558	503	**8%**
United Kingdom	5465	0.463	5887	**-7%**	5705	0.467	6157	**-7%**
United States of America	35706	0.456	37061	**-4%**	36875	0.456		
Ammonia								
France	2130	1.449	2443	**-13%**	2299	1.465		
Hungary								
New Zealand								
United Kingdom	1170	1.465	1379	**-15%**	1241	1.460	814	**52%**
United States of America	23777	1.829	24171	**-2%**	24461	1.825		
Aluminium								
France	446	1.198	467	**-5%**	457	1.202		
Hungary	46	1.847	174	**-73%**	85	2.834		
New Zealand	474	1.736	493	**-4%**	491	1.721	504	**-3%**
United Kingdom	369	1.549	372	**-1%**	372	1.549	384	**-3%**
United States of America	4961	1.470	5258	**-6%**	5258	1.470		

The estimated emission factors presented above are calculated by using the party’s emission data and production data from the USGS. The much higher error for CO_2 emissions from primary aluminium production in Hungary is caused by the fact that the reported emissions in 1996 are three times higher than in the proceeding years, yet the aluminium production according to the USGS remains rather constant.

Most parties do not (yet) report the activity data. Therefore the activity data from the USGS

were used. Additionally, the difference between reported activity data from various sources is usually small, around several percent, so the estimated emission factors are expected to be little disturbed by differences between activity rates used by parties and the activity rates from other sources.

The deviations of the estimated emissions of CO_2 from reported cement, ammonia and aluminium production emissions were calculated and presented above. The deviation is expressed as the difference between the calculated and the reported emissions (calculated minus reported) divided by the reported emissions.

Estimated emissions differ from as much as 78% for the production of aluminium in Hungary in 1996 to less than one percent for the production of cement in the United Kingdom. The differences can be explained from country specific situations, like applied technology, raw materials and utilisation of emission abatement technologies. To hold on to the country specific emission factors, activity rates could be used to calculate scaling factors (see method C). In cases where production data are not available, other driving factors should be used.

B. Estimation based on Annex B averages and driving factor

When activity rates (production data) are not available, other driving factors can be used to assess the emissions in missing years. Suitable driving factors could be economic production rates, energy input, labour input etc. Such data are available from the United Nations (UN), the World Bank (WB, 1999), the World Resources Institute (WRI, 1994) and the International Energy Agency (IEA, 1999).

World energy statistics are reported by the IEA data. They cover energy data for both OECD and non-OECD countries, covering the period from 1960 to the most recent year 1997. Both the World Bank and the World Resources Institute publish social-economic and population data on an annual base in respectively the World Development Indicators (WB 1999) and the World Resources (WRI, 1994)

In the following example industrial value added (constant 1995 USD) is used as a driving factor (WB, 1999).

Table III-3: Industrial value added in 1995 constant U.S. dollar*

Industrial value added (constant US $)								
	1990	1991	1992	1993	1994	1995	1996	1997
France	4.06E+11	4.04E+11	3.98^{E}+11	3.85E+11	3.95E+11	4.08E+11	4.09E+11	4.15E+11
Hungary	1.35E+10	1.12E+10	1.06^{E}+10	1.08E+10	1.14E+10	1.21E+10	1.23E+10	1.36E+10
New Zealand	*1.61E+10*	*1.59E+10*	*1.61E+10*	*1.71E+10*	*1.80E+10*	*1.87E+10*	*1.92E+10*	*1.96E+10*
United Kingdom	*3.14E+11*	*3.08E+11*	*3.07E+11*	*3.13E+11*	*3.26E+11*	*3.35E+11*	*3.43E+11*	3.63E+11
United States of America	1.62E+12	1.57E+12	1.58^{E}+12	1.63E+12	1.76E+12	1.89E+12	2.03E+12	2.10E+12

* not all the data are from (World Bank,1999) some values were estimated using interpolation and extrapolation, (*italic*).

The industrial value added is used to calculate country specific emission rates from the reported emissions. The resulting emission rates are presented below.

Table III-4: Calculated emission rates using reported emissions and industrial value added from the World Bank (WB, 1996.

CO_2 Emission rate (g/US $)	*Calculated emission rates*							
	1990	1991	1992	1993	1994	1995	1996	1997
Time since base year (1990)	0	1	2	3	4	5	6	7
Cement								
France	25.7	24.5	22.4	21.3	21.2	20.2	19.7	
Hungary		113.2	105.1	117.2	122.1	118.7	111.7	
New Zealand	22.8	21.6	25.2	27.0	27.0	27.0	26.3	25.6
United Kingdom	21.3	17.8	16.3	16.2	17.9	17.2	17.2	16.9
United States of America	20.2	20.4	20.4	20.8	20.1	19.1	18.2	
Ammonia								
France	6.1	6.2	5.5	6.0	5.9	5.7	6.0	
Hungary								
New Zealand								
United Kingdom	4.3	4.4	4.5	4.4	4.2	4.1	4.0	2.2
United States of America	14.3	14.9	15.4	14.4	13.8	12.5	11.9	
Aluminium								
France	1.0	0.9	1.3	1.4	1.2	1.1	1.1	
Hungary		10.5	4.7	4.8			14.1	
New Zealand	28.5	28.6	26.3	27.3	26.0	25.2	25.7	25.7
United Kingdom	1.4	1.5	1.2	1.2	1.1	1.1	1.1	1.1
United States of America	3.7	3.9	3.8	3.3	2.8	2.6	2.6	

The CO_2 emissions for cement production, ammonia and aluminium production in 1996 and 1997 were estimated using average emission rates and country specific driving factors. The calculated average emission rates are also presented in the table below.

The average emission rates were calculated for each sector by averaging the available emission rates from other countries. As can be seen from the table III-4, the country specific emission rates vary largely among countries. Some countries have rather deviating emissions rates, indicating a different sector structure.

The resulting emissions (average emission rate multiplied by the index industry value added of the country) are given below, together with the calculated deviations with respect to the emissions reported by parties. Positive deviations result from a higher estimate and a negative deviation corresponds with a lower estimate.

Table III-5: Estimated emissions using Annex B averaged emission rates and emissions reported by parties. The “error” indicates the deviation of the obtained estimates from the values reported by parties

CO_2 Emissions (Gg)	*Annex B averaged emission rates*							
	1996				1997			
Average based on		1990-1995				1990-1996		
	Estimate	emission rate (g/US $)	Reported	"error"	Estimate	emission rate (g/US $)	Reported	"error"
Cement								
France	15428	37.73	8042	**92%**	15264	36.81		
Hungary	464	37.73	1374	**-66%**	499	36.81		
New Zealand	723	37.73	503	**44%**	723	36.81	503	**44%**
United Kingdom	12945	37.73	5887	**120%**	13379	36.81	6157	**117%**
United States of America	76659	37.73	37061	**107%**	77395	36.81		
Ammonia								
France	3283	8.03	2443	**34%**	3220	7.76		
Hungary	99	8.03			105	7.76		
New Zealand	154	8.03			152	7.76		
United Kingdom	2755	8.03	1379	**100%**	2822	7.76	814	**247%**
United States of America	16312	8.03	24171	**-33%**	16324	7.76		
Aluminium								
France	3334	8.15	467	**614%**	3507	8.46		
Hungary	100	8.15	174	**-42%**	115	8.46		
New Zealand	156	8.15	493	**-68%**	166	8.46	504	**-67%**
United Kingdom	2797	8.15	372	**652%**	3074	8.46	384	**701%**
United States of America	16565	8.15	5258	**215%**	17784	8.46		

The deviations of the estimated CO_2 emissions from reported cement, ammonia and aluminium emissions are rather large. This is caused by the fact that average emission rates are applied, which in general differ from the originally calculated emissions rates especially when emissions rates differ much among countries.

C. Extrapolation based on a driving factor

The calculated emission rates, presented in the second method can be used to make extrapolations in the sense that driving factors of a recent year are used to calculate missing emissions. One has to assume in time constant emission rates (that is emissions per unit of driving factor). The emission rates for the missing years are set to be equal to the most recent year and the predicted emissions are calculated using the specific driving factors of the year to be predicted.

An alternative option is to extrapolate the emission rates from the available emission rate time series using regression functions. Note that here the regression is applied to the emission *rate* not to the emissions themselves.

The trend in emission rates for the cement industry is given in the figures below. It shows some non-linear relationships for New Zealand, United Kingdom and Hungary in the period before 1994. The trend in emission rates for France and the USA is more or less linear for the whole period.

In general one could state that the linear relation between the driver industrial value added and the carbon dioxide emissions roughly holds for all countries except for Hungary.

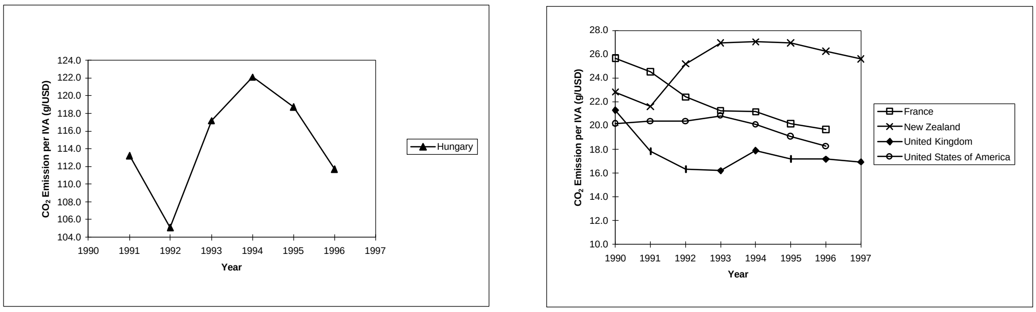

Figure III-1a & b: Trends in emission rates for the cement industry.

Various functions can be fitted to the data. Which model/equation should be fitted to the data depends on the best fit or should be a model, which explains the trends and describes the forces behind the trends best.

The table below gives the estimated coefficients of the linear regression function. The function will be used to estimate the emission rates in the missing year, which in turn have to be multiplied by the driving factor of the missing year to give the estimated emission. The extrapolation procedure can also be directly applied to the emission time series in order to directly calculate the emissions in the missing year with the derived regression functions, see method E.

The regression function has the following form: $y = ax + b$

in which:	y	Emission rate in year x
	x	Number of years since the base year (year - 1990)
	a and b	Coefficients of the regression function

Table III-6: Estimated regression functions for CO_2 emission rates for the cement industry.

	Linear y = ax + b		
	a	B	R^2
France	-1.000	25	0.933
Hungary	1.091	111	0.115
New Zealand	0.575	23	0.471
United Kingdom	-0.352	19	0.287
United States of America	-0.305	21	0.544

CO_2 emissions and N_2O emissions from the production of nitric acid and adipic acid are estimated for 1996 and 1997 by applying the linear regression functions for the emission rates, as tabulated above. Emission rates found by regression are multiplied by the value of the driver (industry value added). Emission estimates for 1996 and 1997 are tabulated below.

Table III-7: Estimated emissions using linearly regressed emission rates and industry value added as driver. Also included are the deviations (“error”) from the emissions reported by parties.

CO_2 Emissions (Gg)	*Extrapolating using Industrial Value Added*							
		1996				1997		
regression based on period	Estimate	1990-1995 number of data points	Reported	"error"	Estimate	1990-1996 number of data points	Reported	"error"
Cement								
France	9545	6	8042	**19%**	9269	7		
Hungary	1506	5	1374	**10%**	1623	6		
New Zealand	545	6	503	**8%**	547	7	503	**9%**
United Kingdom	6122	6	5887	**4%**	6279	7	6157	**2%**
United States of America	38388	6	37061	**4%**	38321	7		
Ammonia								
France	2413	6	2443	**-1%**	2459	7		
Hungary		0				0		
New Zealand		0				0		
United Kingdom	1382	6	1379	**0%**	1387	7	814	**70%**
United States of America	24000	6	24171	**-1%**	24184	7		
Aluminium								
France	398	6	467	**-15%**	394	7		
Hungary	267	3	174	**53%**	277	4		
New Zealand	478	6	493	**-3%**	491	7	504	**-3%**
United Kingdom	347	6	372	**-7%**	330	7	384	**-14%**
United States of America	4217	6	5258	**-20%**	4737	7		
N_2O Emissions (Gg)								
Nitric Acid								
France	12.95	6	14.16	**-9%**	12.78	7		
Hungary		0				0		
New Zealand		0				0		
United Kingdom	13.04	6	12.48	**4%**	11.78	7	12.01	**-2%**
United States of America	46.68	6	45.00	**4%**	46.44	7		
Apidic Acid		0				0		
France	43.05	6	56.73	**-24%**	45.33	7		
Hungary		0				0		
New Zealand		0				0		
United Kingdom	61.25	6	55.22	**11%**	61.14	7	57.31	**7%**
United States of America	65.89	6	63.00	**5%**	65.21	7		

The estimated emissions, obtained by applying linear extrapolation to the emission rate, are compared to the emissions reported by parties. Deviations range from minus 25% to 70%. Especially the carbon dioxide predictions for ammonia production in the United Kingdom and the aluminium production in Hungary show rather large deviations. The large “error” of the predicted emission for ammonia in the United Kingdom is caused by the lower reported emission for 1997 compared to the preceding years, see also method E. The large “error” of prediction for aluminium in Hungary can be explained by the large fluctuations in the reported emission data, i.e., bad fit of the regression function.

D. Linkages of emissions between sources and gases

Using the reported carbon dioxide emissions, see method 1, emission can be estimated using emission factor quotients. Emission factor quotients for SO_2 and NO_x, which are derived from the default (average) IPCC emission factors are shown below. SO_2 and NO_x are not directly relevant to the Kyoto Protocol but are useful to illustrate the principle.

Table III-8: calculated emission factor quotients using IPCC emission factors.

	Emission quotients	
	SO_2/CO_2 [kg/kg]	NO_x/CO_2 [kg/kg]
Cement	6.02E-04	
Ammonia	1.94E-05	
Aluminium	9.15E-03	1.30E-03

Table III-9: Estimated SO_2 emissions based on reported CO_2 emissions.

Estimated SO_2 emissions (Gg)	*Emissions estimated using substance emission quotients*							
	1990	1991	1992	1993	1994	1995	1996	1997
Cement								
France	6.3	6.0	5.4	4.9	5.0	5.0	4.8	
Hungary		0.8	0.7	0.8	0.8	0.9	0.8	
New Zealand	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3
United Kingdom	4.0	3.3	3.0	3.1	3.5	3.5	3.5	3.7
United States of America	19.6	19.2	19.3	20.4	21.3	21.7	22.3	
Ammonia								
France	0.05	0.05	0.04	0.04	0.04	0.05	0.05	
Hungary								
New Zealand								
United Kingdom	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02
United States of America	0.45	0.45	0.47	0.45	0.47	0.46	0.47	
Aluminium								
France	3.7	3.2	4.7	4.8	4.3	4.1	4.3	
Hungary		1.1	0.5	0.5			1.6	
New Zealand	4.2	4.2	3.9	4.3	4.3	4.3	4.5	4.6
United Kingdom	4.1	4.2	3.5	3.4	3.3	3.4	3.4	3.5
United States of America	54.5	55.4	54.4	49.7	44.4	45.4	48.1	

Using this method, the sulphur dioxide emission are estimated and compared with the SO_2 emissions reported by parties. For the considered countries, SO_2 emissions were only reported for cement production and the production of primary aluminium by New Zealand, France, and the United Kingdom.

Table III-10: Estimated SO_2 emissions compared to the SO_2 emissions reported by parties.

Estimated SO_2 emissions (Gg)	Emissions estimated using substance emission quotients							
	1990	1991	1992	1993	1994	1995	1996	1997
Cement								
France								
Hungary								
New Zealand	-73%	-73%	-71%	-70%	-68%	-69%	-70%	-70%
United Kingdom								
United States of America								
Aluminium								
France	-34%	-19%	-19%	-19%	-19%	-19%	-19%	
Hungary								
New Zealand	-30%	-27%	-25%	-27%	-27%	-34%	-30%	-35%
United Kingdom	-6%	-6%	-6%	-6%	-6%	-6%	-6%	-6%
United States of America								

E. Interpolation and extrapolation

Extrapolation requires rather complete time series to provide a trend, if present, in the emission data, driving factors or emission factors. Extrapolating emission data time series requires only the reported emissions. When extrapolating emission rates or a driving factor, both emission data and driving factors should be available (method C). In the latter case driving factors for the missing year should also be available.

Table III-11 provides the reported emissions. The emission time series are used to fit a linear function to the historical data, see the figure below. The function describes a straight lines and has the form y = ax + b, where y is the CO_2 emission, a and b are coefficients of the function and x is the year for which the emission were reported.

Table III-11: Reported CO_2 emissions (Gg) for the cement, ammonia and aluminium industry.

CO_2 Emissions (Gg)	*Reported emissions*							
	1990	1991	1992	1993	1994	1995	1996	1997
Cement								
France	10427	9902	8908	8191	8366	8233	8042	
Hungary		1265	1118	1267	1397	1438	1374	
New Zealand	367	343	405	461	487	503	503	503
United Kingdom	6693	5499	5006	5069	5842	5766	5887	6157
United States of America	32626	31897	32149	33945	35379	36125	37061	
Ammonia								
France	2477	2500	2196	2314	2324	2328	2443	
Hungary								
New Zealand								
United Kingdom	1358	1358	1379	1379	1379	1379	1379	814
United States of America	23138	23361	24391	23399	24316	23681	24171	
Aluminium								
France	400	351	513	523	471	447	467	
Hungary		117	50	52			174	
New Zealand	458	455	423	467	468	470	493	504
United Kingdom	450	456	380	371	359	369	372	384
United States of America	5951	6058	5942	5432	4850	4961	5258	

The figure below shows both reported data on CO_2 emissions from the ammonia production and the fitted straight line for France and the United Kingdom. The coefficients of the regression functions are given together with the correlation coefficient, R-squared (R^2) in table III-12. R^2 indicates the degree to which the variance in the emissions correlates with the variance in the year. A low figure corresponds with a pour correlation and a high number corresponds with good correlation.

As can be seen from data, which were reported by the United Kingdom, attention has to be paid to outliers. The reported 1997 emission deviates from the earlier reported emissions and this possible outlier has a large influence on the appropriateness of the estimated regression function and consequently on the extrapolated emissions. Statistical test can be performed to determine whether a value is an outlier.

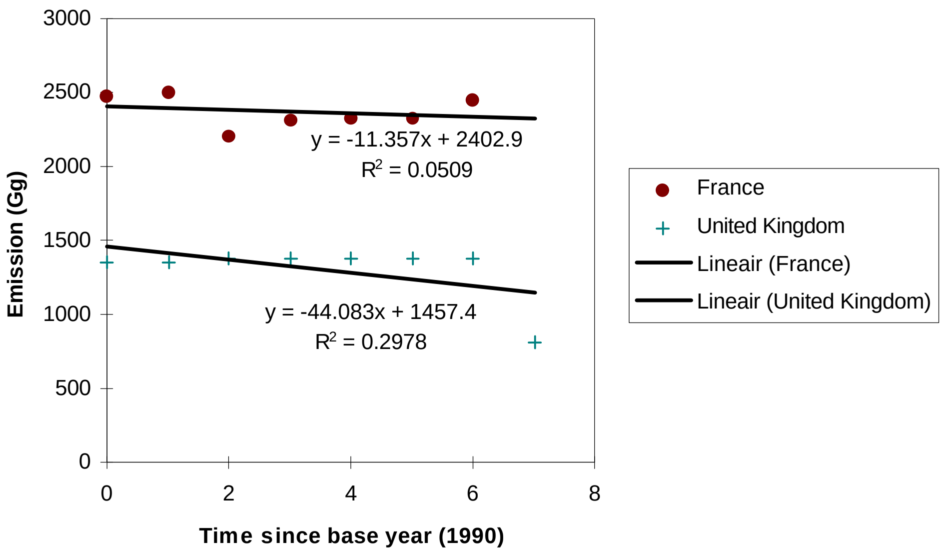

Figure III-2: CO2 emissions from the production of ammonia

The table below shows the estimated regression coefficients of the linear function. There were no reported CO_2 emissions related to ammonia production in Hungary and New Zealand. The regression coefficients for emissions of carbon dioxide from ammonia production in the United Kingdom are based on the reported time series, leaving out the 1997 value. As can be seen from the figure above, this results in a better fit and complete different regression coefficients.

Table III-12: The estimated coefficients of the linear regression functions based on reported CO_2 emissions from cement, ammonia and aluminium production.

y = ax + b	a	b	R^2
Cement			
France	-394	10,049	0.821
Hungary	47	1,146	0.556
New Zealand	25	360	0.847
United Kingdom	15	5,688	0.004
United States of America	892	31,491	0.881
Ammonia			
France	-11	2,403	0.051
Hungary			
New Zealand			
United Kingdom	-44	1,457	0.298
United States of America	131	23,387	0.308
Aluminium			
France	13	416	0.198
Hungary	17	47	0.380
New Zealand	8	440	0.604
United Kingdom	-11	431	0.505
United States of America	-192	6,068	0.691

The regression functions are used to extrapolate emissions by simply filling out years in the regression function which are given in the above table, the results for CO_2 and N_2O emissions in 1996 and 1997 are tabulated below.

Table III-13: Estimated CO_2 emissions for cement, ammonia and aluminium production and N_2O emissions from nitric acid and adipic acid production, using linear regressed time series on reported emissions together with reported the reported emissions and the "error" of the estimates.

CO_2 Emissions (Gg)	*Extrapolating the time series*							
		1996				1997		
regression based on period	Estimate	1990-1995 number of data points	Reported	"error"	Estimate	1990-1996 number of data points	Reported	"error"
Cement								
France	7375	6	8042	**-8%**	7291	7		
Hungary	1484	5	1374	**8%**	1473	6		
New Zealand	544	6	503	**8%**	554	7	503	**10%**
United Kingdom	5292	6	5887	**-10%**	5531	7	6157	**-10%**
United States of America	36660	6	37061	**-1%**	37739	7		
Ammonia								
France	2241	6	2443	**-8%**	2323	7		
Hungary		0				0		
New Zealand		0				0		
United Kingdom	1389	6	1379	**1%**	1388	7	814	**71%**
United States of America	24173	6	24171	**0%**	24303	7		
Aluminium								
France	511	6	467	**9%**	503	7		
Hungary	-58	3	174	**-134%**	166	4		
New Zealand	471	6	493	**-4%**	488	7	504	**-3%**
United Kingdom	327	6	372	**-12%**	333	7	384	**-13%**
United States of America	4624	6	5258	**-12%**	4727	7		

N_2O Emissions (Gg)								
Nitric Acid								
France	15.97	6	14.16	**13%**	15.49	7		
Hungary		0				0		
New Zealand		0				0		
United Kingdom	13.37	6	12.48	**7%**	12.69	7	12.01	**6%**
United States of America	44.80	6	45.00	**0%**	45.86	7		
Apidic Acid								
France	68.34	6	56.73	**20%**	67.41	7		
Hungary		0				0		
New Zealand		0				0		
United Kingdom	37.43	6	55.22	**-32%**	42.77	7	57.31	**-25%**
United States of America	62.93	6	63.00	**0%**	64.29	7		

IV. Conclusions

Emissions can be estimated by applying the methods described in chapter II. Which method should be applied depends on the availability of relevant data on drivers. Each method has it own strong and weak points.

Method A uses default or average emission factors which do not always account for the country specific situation. But method A uses the emission driver (production data) most close to the actual process.

Other methods use drivers more distant from the actual emission source or process. This introduces uncertainty because the relation between the driver and the emissions is not always straightforward. Even more uncertainty may be introduced when no data on drivers is available and estimates are based on time series extrapolation. No information on technological or sector developments is included in such an estimate. These estimates are only base on the observed time series.

The performance of each method depends on the availability of proper driver data and the data quality. The deviation of the various methods with respect to the emission gives an indication of the performance of the estimation methods. The deviations of the estimates in the year 1996 have been used to graphically present the deviations.

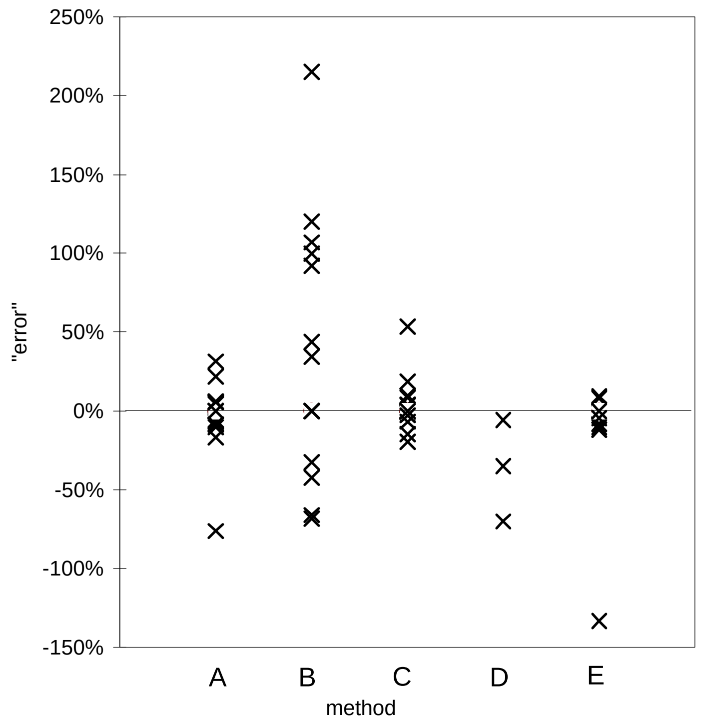

Figure IV-1: Deviations of emissions using methods A to E from the emission estimates reported by parties.

Comparison of the different methods in the above graph shows that there is not much difference between the methods used with the exception of method B. The deviations are in the range of several times ten percent for all methods with the comparable spread for method A and method E apart from one special outlier which occurs in method A (negative), C (positive) and E (negative). In all cases it concerns the emissions from aluminium production in Hungary. Method D shows negative deviation for all estimates, indicating an underestimation of the method used compared with emissions as reported by the countries. Method B shows the largest deviations.

The deviations of the emission estimates for the primary aluminium production of France and the United Kingdom which amount about 600% were left out of figure IV for better view of the other results.

Obstacles to obtain revised technical estimates are in some cases the availability of information on proper drivers. Data on drivers may not always be available in readily accessible public literature.

Although these conclusions are based on an analysis of a subset of industrial sources, it should be noted that these sectors might represent several others. The examples were carried out for mineral industry (cement), primary metal production (aluminium) and bulk chemicals (ammonia). Some regression results for fertiliser were obtained showing similar deviations. It is therefore expected that similar results will be obtained for other industrial sectors.

The overall conclusion therefore will be that emission estimates for industrial sources in Annex B countries might be obtained from using available activity data and either default emission factors or Annex B or even country specific emission factors or by using other drivers. The uncertainties in such estimates might be of the order of one third of the estimated value, although in some cases, errors of a few hundred percent are observed. Application of these methods therefore should always be performed with care.

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