Use of a PRTR Emission Inventory in Assessing the Benefits of Abatement Policies in Industry

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ABSTRACT

Facility level emission reports in Europe are available from the European Pollution Emissions Register (EPER, http://www.eper.ec.europa.eu/eper). This data set is a so-called Pollutant Release and Transfer Register (PRTR). EPER is in many respects comparable to the US Toxics Release Inventory. This study shows a novel use of such PRTR facility level emission inventory data in assessing the potential benefits of existing environmental legislation.

The paper presents the results of a recent study to asses the potential benefits of full implementation of emission abatement policies in power plants in the European Union Member States. The study compares emissions reported by the power plants at facility level (EPER) with emissions estimated through linking to information obtained from a commercial database (Platts, http://www.platts.com/). This approach allows for estimating the expected emissions when all 450 power plants in the study would have installed combustion technologies that are in line with the "Best Available Techniques" as defined within the European Union's IPPC Directive or with the emission limit values as set for new plants in the EU Large Combustion Directive.

Comparison with the reported emissions shows that emissions would have been substantially lower (more than a factor of two for NO_x and SO_2) if the emission abatement would indeed have been implemented in 2004.

INTRODUCTION

Industrial Combustion and European Air Pollution Policy

Emissions from industrial combustion contribute considerably to the emissions of several pollutants to the atmospheric environment. The industrial combustion source categories includes:

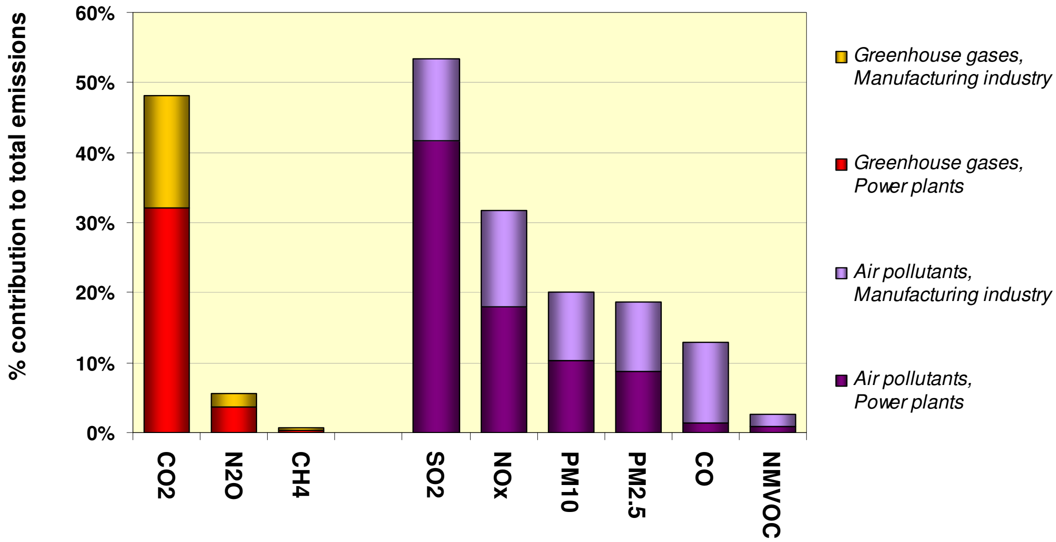
- emissions from the energy industry: power plants (IPCC source category 1.A.1.a[1]) and refineries (IPCC source categories 1.A.1.b)
- emissions due to combustion in manufacturing industries (IPCC source category 1.A.2).

Figure 1 shows that the power plants contribute more than 30 % to the European Union's carbon dioxide (CO_2) emissions, over 40 % to those of sulphur dioxide (SO_2) and almost 20 % to nitrogen oxide (NO_x) emissions in 2005. The contributions to particulate emissions by this source amount about 10 % of the total emissions. The contributions from combustion in the manufacturing industry (including refineries) are smaller, but also considerable. In total, these two source categories contribute almost to 50 % of the European CO_2, to more than half of the SO_2 emissions, to over 30 % of the NO_x emissions and to about 20 % of the total particulate emissions in the European Union.

Taking this high contribution into account, the European Union has developed over time a series of air pollution policies and measures. The most recent updates of these include:

- Large Combustion Plant (or "LCP") Directive[2]

Figure 1. Contribution of emissions from power plants to the total EU 27 emissions of air pollutants in 2004 (data from [1])



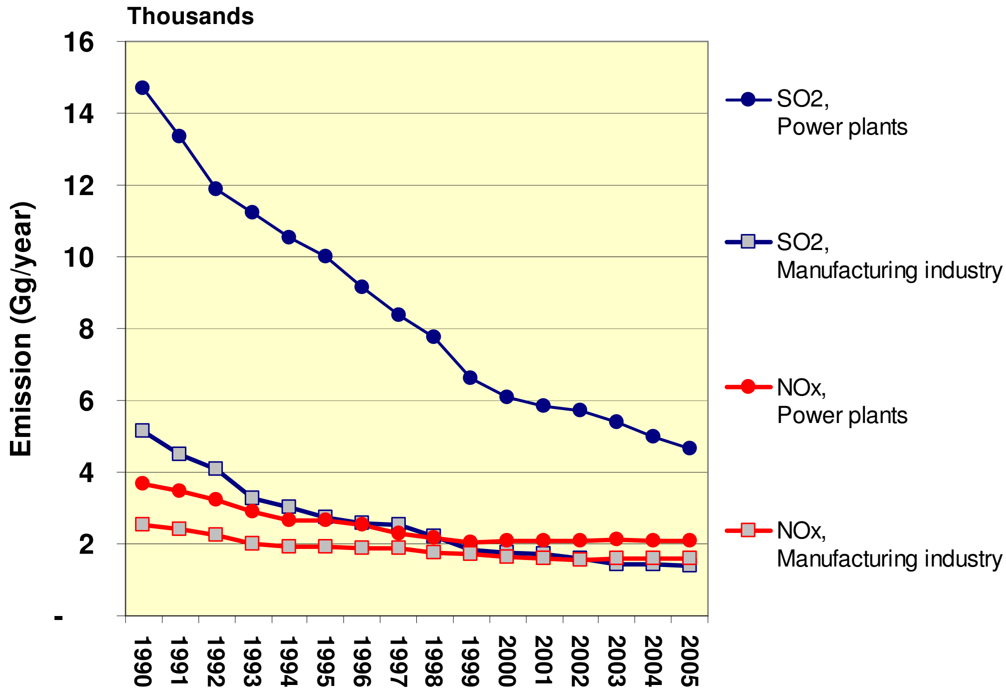
The LCP Directive sets limit values for SO_2, NO_x and "dust" emissions. The directive requires national authorities in European Union Member States to issue permits to any operator of large combustion plants ($\geq$ 50 MW_{th}) defining the conditions relating to compliance with the emission limit values.

- Integrated Pollution Prevention and Control (or "IPPC") Directive[3]
  The IPPC Directive has a broader scope and includes other industrial processes in addition to combustion and other pollutants in addition to SO_2, NO_x and dust. In addition, IPPC is implementing an approach that integrates criteria for environmental performance in different environmental compartments (not only air). The Directive introduces the concept of Best Available Techniques ("BAT") into the legislation and requires competent authorities to prescribe such BAT techniques to attain an overall environmental performance in permits for operating industrial facilities. BAT is defined for major industrial processes in so-called BAT Reference (BREF) documents[4]. These documents provide "*associated emission levels*", to be seen as emission levels that can technically be achieved when applying the Best Available Techniques.

Recently the European Commission proposed to integrate the IPPC Directive and five other industry relevant pieces of legislation into one new recast Directive on Industrial Emissions[5]. This recasting of directives into one single new one does not significantly change the objectives and the policy tools.

Since the introduction of these European policies, emissions of air pollutants from these source categories have significantly decreased (**Figure 2**). The SO_2 and NO_x emissions from power plants in 2005 were down to about 32 % and 57 % of what they were in 1990, despite the fact that the fuel input into thermal power stations in the 27 European Union Member States increased by 12 % in the same time period[6].

Figure 2. Trends in emissions of NO_x and SO_2 in the European Union Member States (data from 3)

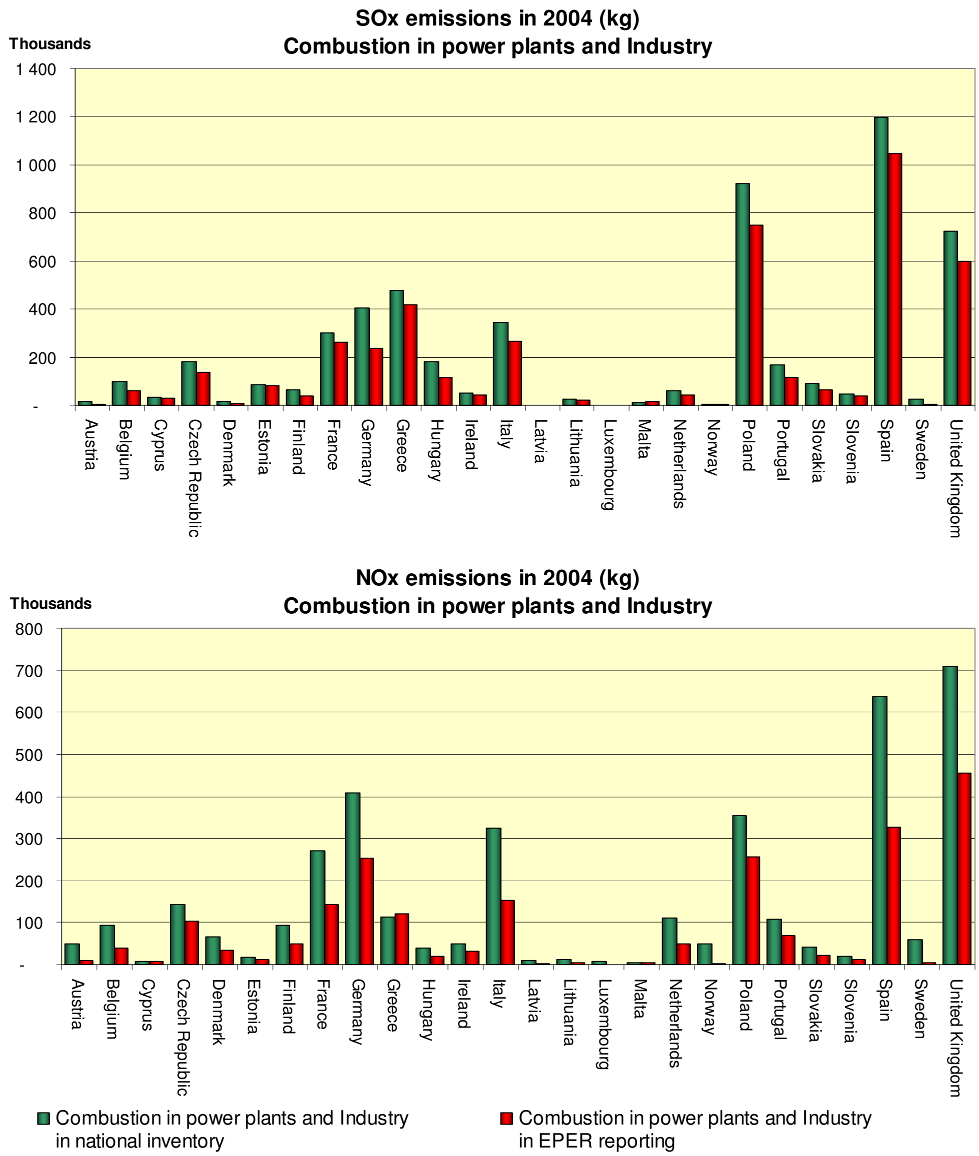


Facility Level Emissions Reporting

A second line of policies regarding major industrial air pollution sources is derived from the "Community Right to Know" approach. While preparing for obligations under the Aarhus Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters[7], the European Union, has set up an emissions reporting system that requires Member States to produce a triennial report, which covers the emissions of 50 pollutants to air and water from larger industrial facilities. The resulting European Pollutant Emissions Register (EPER) is publicly available on Internet and contains emissions data for more than 11 000 facilities in 26 countries[8]. EPER now is further developed into the European Pollutant Release and Transfer Register (E-PRTR) to fully respond to the obligations of the PRTR Protocol, established under the Aarhus Convention.

Figure 3 shows that this register includes a large fraction of all SO_2 and NO_x emissions from industrial combustion (power plants and combustion in manufacturing industries) reported in national inventories[9]. For most countries the fraction of national emissions in these source categories that is reported by individual facilities is about 40 to 60 %. The remaining 60 to 40 % of the emissions might be due to smaller combustion units, not included in EPER.

Figure 3. Comparison of SO_2 and NO_x emissions from industrial combustion in Europe as reported in national inventories with facility level emission reports (from 10)



Objective of this Study

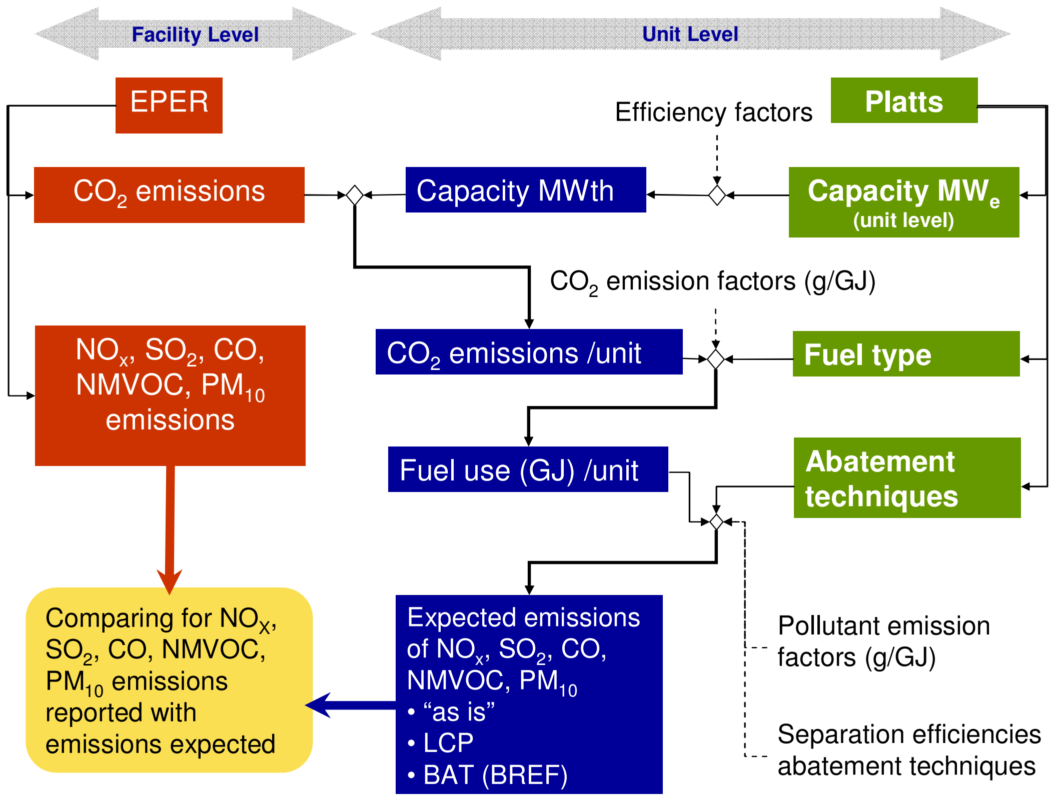
In this study we use the information available in the European Pollutant Emissions Register to assess the potential emission reduction of NO_X and SO_2 due to the implementation of Best Available Techniques in European fossil fuel fired power plants. The paper is largely based on an earlier study[10], performed within the 2007 work program of the European Topic Centre on Air and Climate Change (http://air-climate.eionet.europa.eu/) of the European Environment Agency (http://www.eea.europa.eu).

METHODS

Overview

In this study we analyse emission reports from individual facilities as to their implementation of Best Available Techniques (BAT). To assess the implementation of BAT in large combustion installations, emissions at these installations (as included in EPER) need to be individually compared with the emissions expected if BAT were installed at these plants. This requires additional information on type and quantities of fuels combusted, which is not available in the European Pollutant Emissions

Figure 4. Approach used in the study



Register (EPER). In this study we used the database from Platts[11], providing technical details of power plants all over the world. Combining the information on emissions in EPER with data on fuel types, capacities and abatement technologies in Platts provides all what is necessary to perform the assessments for fossil fuel fired power plants in the European Union for the year 2004. The link between EPER and Platts is based on the name and the location of the companies. **Figure 4** provides an overview of the calculations performed in this study. More details are provided below. A similar database as the Platts one for power plants is not available for other industrial combustion. The analyses in this paper therefore are limited to the European power plants.

Table 1. Emissions of the 450 selected EPER facilities in relation to all 1268 combustion facilities in the EPER 2004 dataset (kt)

Pollutant	Emission from the 450 selected power plants	Total reported emission of all Combustion facilities in EPER	% coverage of selection
NO_x	1 494	1 986	75%
CO	207	257	80%
NMVOC	6	9	71%
PM_{10}	91	128	71%
SO_2	2 773	3 771	74%
CO_2	1 006 598	1 259 325	80%

Emission data

Facility level emission reports included in the 2004 reporting cycle of EPER[10] are used as the source of emissions data for this study. The data include emissions from 450 power plants in the 25 pre-2006 European Union Member States (Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, and United Kingdom). **Table 1** shows that these 450 power plants contribute to 70 to 80 % of all combustion related emissions reported in EPER.

Fuel used

Information on the type of fuel used was taken from the Platts database which contains information on single units within each facility, in contrast to the EPER database which contains information on facility level emissions only. In contrast to the EPER database, the Platts database contains information on single units within each facility. **Table 2** shows the type of fuels used in the 1 482 units in the 450 power plants included in this study. Natural gas is the most frequently used fuel in the power plants in the European Union. It is used in 511 units of 220 power plants in the study. Bituminous hard coal is used in 370 units in 147 power plants and heavy fuel oil in 239 units in 64 power plants.

The quantity of fuel combusted for each unit can be estimated from the CO_2 emissions at the unit, using CO_2 emission factors[1]. EPER however does only provide CO_2 emissions at the facility level. Assuming that hard coal is mainly used at base load power plants, fuel oil at middle load and gas at peak load power plants, we use the unit level capacities, as stored in the Platts database to split the CO_2 emission as reported in EPER on facility level over the units as given in equation 1:

$$[CO_2]_{unit} = [CO_2]_{facility} \times \frac{Operation\,time_{unit} \times Cap_{unit} \times EF_{CO_2,fuel_{unit}}}{\sum_{all\ units} Operation\,time_{unit} \times Cap_{unit} \times EF_{CO_2,fuel_{unit}}} \qquad (1)$$

Where:

$[CO_2]_{unit}$	=	allocated CO_2 on unit level [kg]
$[CO_2]_{facility}$	=	EPER 2004 reported CO2 on facility level [kg]
Operation $time_{unit}$	=	typical operation time of a unit (= 90 % for hard coal and brown coal, 50 % for fuel oils and 20% for natural gas)
Cap_{unit}	=	capacity rating of unit [MW]
$EF_{CO_2,fuel_{unit}}$	=	fuel dependent emission factor for unit from the IPCC 2006 Guidelines[1].

Table 2. Fuels reported in Platts and number of units identified in the 450 EPER facilities of the EPER 2004 dataset

Fuel type	Fuel	Number of EPER facilities linked to fuel type in Platts	Number of Platts units in selected EPER facilities linked to fuels
Hard Coal	Anthracite and bituminous coal	3	8
	Anthracite or semi-anthracite coal	5	11
	Bituminous coal	147	370
	Bituminous coal and anthracite coal	3	4
	Sub-bituminous coal	5	14
Brown coal	Bituminous coal and lignite (brown coal)	7	10
	Lignite (brown coal)	41	182
	Lignite and bituminous coal	3	12
	Lignite and sub-bituminous coal	2	6
Fuel Oil	Heavy fuel oil (Number 6 oil or bunker)	64	239
	Residual oil	1	1
Other Oil	Diesel oil	8	22
	Distillate oil (also Number 2 oil and light fuel oil)	32	82
Gas	Natural gas	220	511
	Liquefied natural gas	2	10
Total (*)		**450**	**1 482**

(*) Since the Platts database contains information at the unit level, an EPER facility can consist of more than one unit and therefore can be assigned to more than one fuel type. Therefore, the total number of times that EPER facilities are assigned to Platts units (543) is higher than the total number of EPER facilities included in the evaluation.

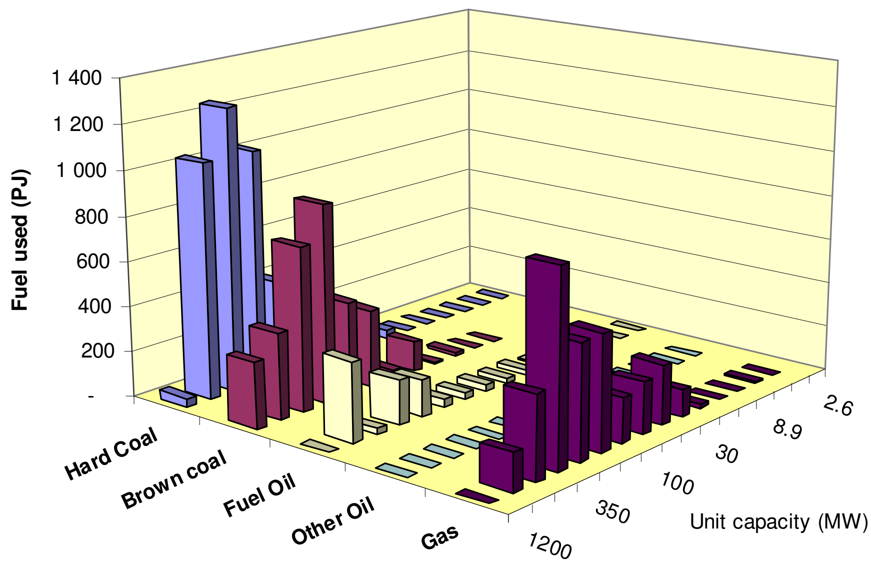
Using equation (1) and the fuel dependent default CO_2 emission factors from the 2006 IPCC Guidelines the amount of fuel in each individual unit can be estimated. **Table 3** compares our estimated power plant fuel input with data obtained from EUROSTAT[7]. The table shows that the power plants in the study cover the majority of the production in power plants in the European Union in 2004. The lower coverage of natural gas fired power plants might be explained by the fact that natural gas indeed is used more frequently in peak load power plants, which might be more frequently be below the EPER threshold capacity (50 MW_{th}), whereas solid fuels and liquid fuels more frequently are used in base load and middle load power plants. Base load power plants are generally larger than peak load power stations. The method to estimate the fuel combusted at individual units seems to fit well with the available statistical data.

Table 3. Fuel combusted at European power plants, included in this study compared with the input into thermal power stations, obtained from Eurostat[7] (PJ in 2004)

Fuel type	Our estimate	EUROSTAT data[7]	Percentage
Hard Coal Brown Coal	4 540 3 270	9 391	83 %
Fuel Oil Other Oil	914 117	1 189	87 %
Gas	2 970	5 680	52 %
Total	**11 800**	**16 260**	**73 %**

A total of 11 800 PJ of fuel is combusted in the 450 power plants in the study. The major fuel is hard coal (4 500 PJ), followed by brown coal (3 300 PJ) and natural gas (3 000 PJ). The amounts of heavy fuel oil and other oils are considerably less: 910 PJ and 120 PJ respectively. The larger amount of fuels is combusted in units with a capacity of a few hundred MW_{th} to just over 1000 MW_{th} (**Figure 5**).

Figure 5. Estimated quantities of fuel used in power plants in Europe as a function of capacity of the unit.



Best Available Techniques (BAT)

Best Available Techniques are defined in the IPPC BAT Reference documents(BREF), published by the European IPPC Bureau. The IPPC BREF document for large combustion plants (LCP BREF[12]) does not define emission limit values, but instead refers to techniques which are considered as being “Best Available Techniques” (BAT) and their Associated Emission Levels (AELs). For these BAT, pollutant concentration ranges are given, indicating the level of emissions that might be expected when BAT is implemented. These AELs are expressed as concentrations in the flue gases. The emission factors, consistent with these AELs for each fuel can be calculated as follows:

$$EF_{fuel,pollutant} = AEL_{fuel,pollutant} \times (Specific\ flue\ gas\ volume) \ \text{[in mass/energy unit]} \quad (2)$$

Table 4 lists the values of the specific flue gas volumes as used in this study. The resulting BREF consistent emission factors are calculated from the fuel and capacity dependent AELs. For the resulting emission factors and further details see Pulles and Appelman[10].

Table 4. Fuel specific flue gas volumes at the indicated excess air conditions

Fuel type	NCV (*) (MJ/kg)	Excess air (% O_3)	Specific flue gas volume (**) (m^3/GJ)
Hard Coal	25.8	6	360
Brown coal	11.9	6	444
Fuel Oil	40.4	3	279
Other Oil	43.0	3	276
Gas	48.0	3	272

(*) Net Calorific Values, from IPCC 2006 Guidelines[1]
(**) Specific flue gas volumes are calculated using the Rosin and Fehling relation[13].

Expected emissions

From the amounts of fuel combusted at each individual unit, expected emissions of the main pollutants are calculated using three different sets of emission factors, modeling one of the following three situations:

- The "as is" case, using
  - EPER emission data where available and
  - the best knowledge of techniques and abatement implemented for each unit from the Platts database to estimate the expected emissions, where EPER data are not available;
- The case where all installations or units have emissions consistent with BAT Associated Emission Level values AEL:
  - EPER emission data for all facilities that appear to have emissions consistent with the AELs
  - emission estimates, using the AELs for all units within facilities that do not have emissions consistent with the BAT AELs.
- The case where all installations or units have emissions consistent with the LCP Directive emission limit values ELV:
  - EPER emission data for all facilities that appear to have emissions consistent with the ELVs
  - emission estimates, using the ELVs for all units within facilities that do not have emissions consistent with the LCP ELVs.

Comparing the emissions expected for these three cases provides an estimate for what full compliance to either the BAT as defined in the IPPC BREF document or the emission limit values as set in the LCP directive would lead to.

RESULTS

The "as is" case

The actual emissions of five major air pollutants from the 450 power plants in this study are presented in **Table 5**. As indicated above, air pollutant emissions not reported in EPER were estimated on the basis of fuel quantities derived from the CO_2 emission and information in the Platts database. These emissions are included in the column "Gap filled" in **Table 5**. This table shows that for this set of facilities:

- Reporting of NO_x and SO_2 is rather complete, since reported emissions amount to 99 % and 97 % respectively of the estimated emissions above the EPER reporting threshold;
- The estimated emissions above the EPER reporting threshold reveal that for a considerable number of facilities, emission reports of CO, NMVOC and PM_{10} might be missing in EPER,

since reported emissions amount to only 47%, 27% and 5% respectively of the gap filled emission estimates.

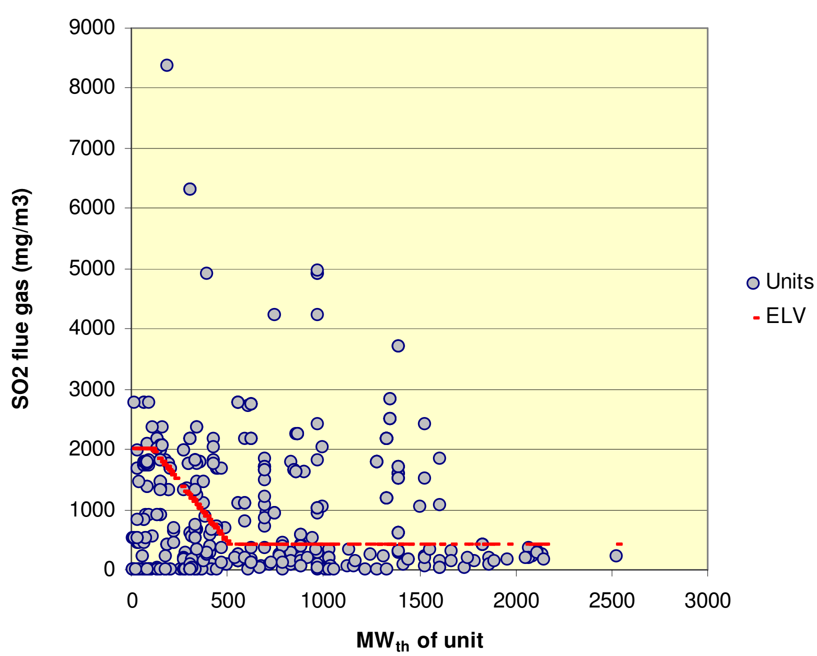
Table 5. Air pollutant reporting in the 2004 EPER data set (for the selected set of 450 facilities)

pollutant	threshold Gg/yr	Emission (Gg/year)				
		Reported in EPER	Gap filled	Estimated above threshold	Missing emission reports	
					Gg	Completeness**
CO_2 *	100	1 004 008	-	-	-	100 %
NO_x	0.1	1 494	1 506	1 506	12	99 %
SO_2	0.15	2 773	2 853	2 851	79	97 %
CO	0.5	207	525	485	278	43 %
NMVOC	0.1	6	59	49	43	12 %
PM_{10}	0.05	91	1 692	1 691	1 601	5 %

* CO_2 emissions are used to estimate fuel use and is available for all 450 power plants in the study.
** "Reported EPER emission"/ "Estimated emission above threshold" in per cent

Caution is required when interpreting the above observations for CO, NMVOC and PM_{10}, since the estimates may have a relatively high uncertainty. The gap filling procedure uses data on installed abatement techniques available within the Platts database. No information is available concerning the quality of these data in terms of the characterization of the abatement installed or the completeness of this data set in this respect. The methodology also employs various parameters (e.g. emission factors) reflecting average values at EU level but which might not be correct for specific facilities. The apparently lower levels of emissions reported for CO and NMVOC are consistent with the findings of the EPER Review 2004 report[9] which found that, with some noted exceptions, emissions of these pollutants in the EPER database are generally significantly lower than the emissions reported by countries to the NEC Directive and the UNECE LRTAP Convention for the industrial combustion sectors.

Figure 6. Comparison of estimated SO_2 flue gas concentrations in solid fuel fired power plants with the LCP Directive's emission limit values



Sulphur dioxide

In many facilities emissions of both CO_2 and SO_2 have been reported. With knowledge of the distribution of fuel combusted over the units within each facility, the ratio between the reported emissions for these two pollutants can be used to calculate an "effective" sulphur content of the fuels and hence SO_2 concentrations in the flue gases can be estimated. The CO_2 to SO_2 ratio in the flue gases can be used to estimate the apparent S to C ratio in the fuel (corrected for abatement installed). From this the SO_2 concentrations in the flue gases can be calculated and compared with the LCP ELVs. The results of this exercise for coal fired combustion plants are presented in **Figure 6** as unit specific sulphur dioxide concentrations in the flue gases.

For all those units in **Figure 6**, where the calculated SO_2 concentrations are above the red line, the emission limit values as set in the LCP Directive are exceeded. It is clear that for a considerable number of units in Europe the requirements of the LCP Directive are not yet met. In 177 out of 405 solid fuel fired power plants, the SO_2 concentrations are higher than expected when the LCP ELVs would be implemented. For about 45 of these the difference is more than a factor of 10.

Implementation of Best Available Techniques (BAT)

The BREF document defines ranges of emission values that are associated with the implementation of Best Available Techniques (BAT), rather than a specific value. In **Table 6** and **Figure 7** these ranges are indicated as upper and lower end of BAT respectively. This table and figure show the potential benefits of introducing technologies that comply with the BAT associated emission levels for all power plants in the study by comparing the emissions as.reported in EPER with those that could be expected if all units in all plants would as a minimum comply with the BAT associated emission levels for NO_x and SO_2.

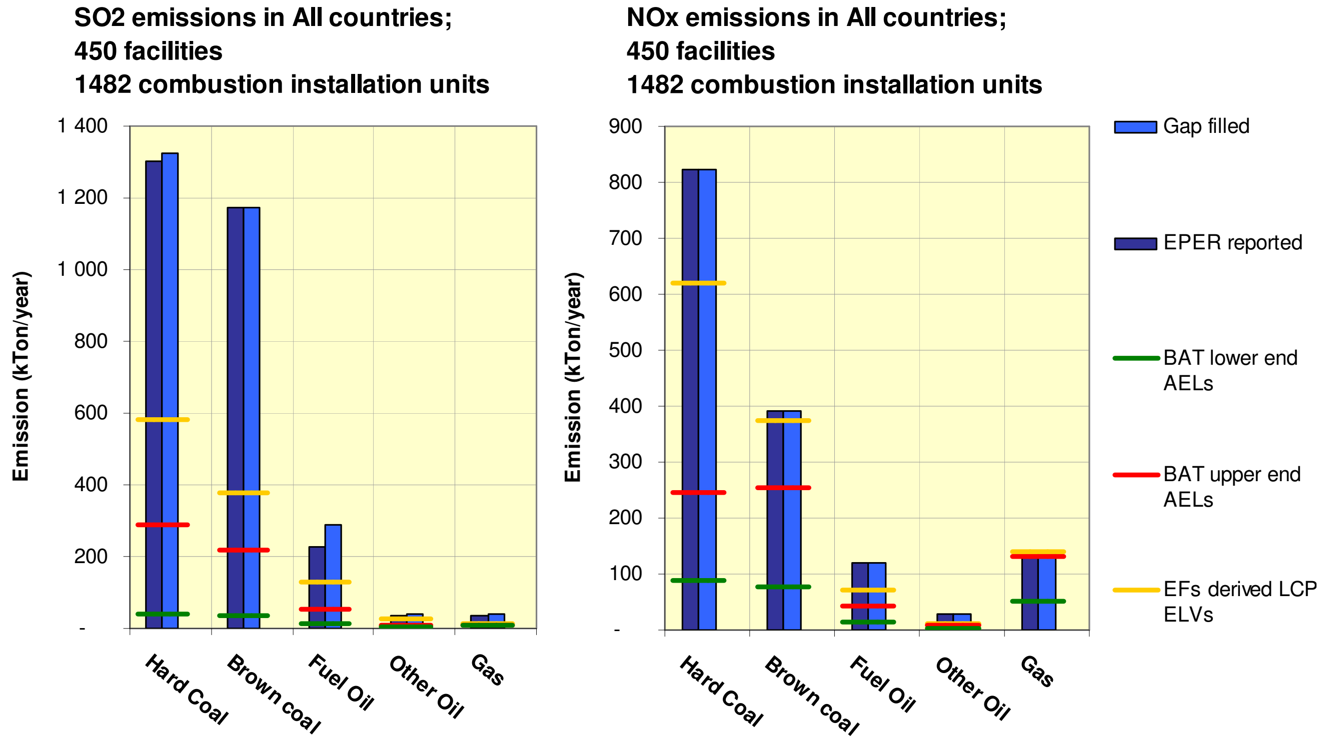
Table 6. Estimated emission reduction in 2004 through full introduction of BAT as described in LCP BREF in large combustion plants (for the selected set of 450 facilities)

	Estimated Emission (kt/year)				
	"as is" gap filled emissions	**Potentially remaining reduced emissions with full introduction of BAT as described in the LCP BREF**			
		Upper end of BAT		**Lower end of BAT**	
pollutant		**kt**	**% of "as is"**	**kt**	**% of "as is"**
NO_x	1 506	622	41 %	198	13 %
SO_2	2 853	566	20 %	98.9	3 %

The following results are observed:

- The emissions of NO_x from the large combustion plants, as included in the EPER 2004 data set, would have been nearly sixty percent lower if all plants would have been performing according to the upper end of BAT AELs in 2004;
- In the more strict interpretation of the BAT described in the LCP BREF (lower end of BAT AELs) the emissions could have been a factor of six lower in 2004 than the emissions reported under EPER;
- For SO_2, the effect of introducing BAT as described in the LCP BREF in all facilities would have decreased emissions from the large combustion plants included in EPER to an even larger extend. For 2004, the emissions could have been more than a factor of five lower for the upper end of BAT AELs and about a factor of thirty for the lower end of BAT AELs.
- By far the largest contributions to these decreases would follow the introduction of LCP BREF AELs at coal and lignite fired large combustion plants.

Figure 7. Reported EPER emissions compared with estimated "as is" emissions and estimated emissions for 2004 corresponding to LCP BREF AELs and LCP Directive ELVs for NO_x and SO_2 (kg)



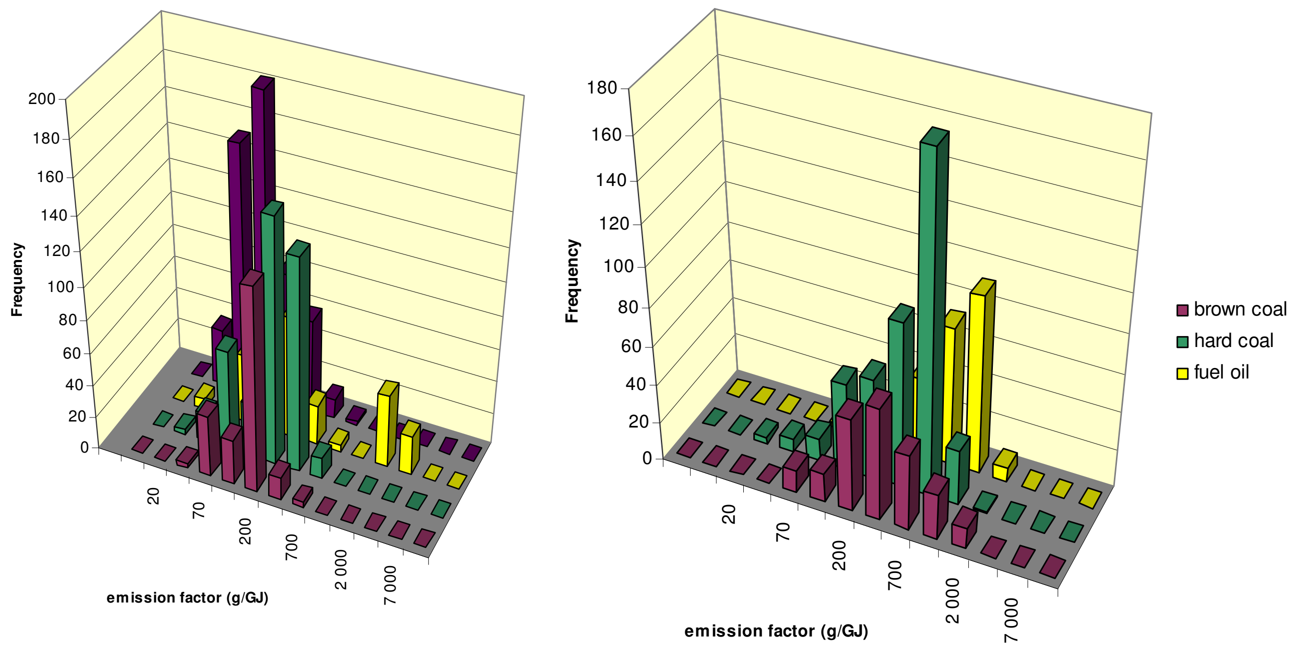
The fuel combusted at the unit level of facilities was estimated on the basis of the allocated CO_2 emissions and the fuel type as identified in the Platts database. Since for all facilities NO_x emission reporting is available, and most facilities have also reported SO_2 emissions (if these are above the thresholds), implied emission factors for SO_2 and NO_x for these facilities can be calculated (**Figure 8**).

It appears that for both NO_x and SO_2 many of the facilities have higher emission rates than the ones associated with BAT:

- For NO_x, BAT emission factors calculated from LCP BREF AELs are generally of the order of 20 to 200 g/GJ, depending on fuel and plant capacity, whereas many implied emission factors are in the range above 50 to 400 g/GJ.
- For SO_2, BAT emission factors calculated from LCP BREF AELs are of the same order of magnitude as was noted for NO_x, but many observed implied emission factors are above 100, and some are even above 1000 g/GJ. More than 50 LCPs show implied emission factors higher than 1000 g/GJ, whereas the BAT emission factors for this pollutant are generally in the order of 3 to 180 g/GJ. Emission reduction measures for these relatively few facilities would decrease the overall LCP emissions considerably.
- The frequency distribution of NO_x implied emission factors is very similar to that reported by Pulles and Heslinga[14], These authors derived facility level implied emission factors for data reported to the Dutch emissions inventory in the period 1990 to 1996, based on NO_x and CO measurements at individual plants.

The frequency distributions of implied emission factors for both NO_x and SO_2 also show consistency with emission factors available in the EMEP/CORINAIR Guidebook[15]. The variability of the implied emission factors is quite large. This may lead to considerable methodological-derived uncertainty at the level of individual facilities and/or in small countries having a low number of

Figure 8. Frequency distribution (vertical) by fuel of implied emission factors (X-axis, g/GJ) for NO_x (left) and SO_2 (right) in the selected EPER facilities as reported in 2004



facilities. This uncertainty is partly caused by the fact that some facilities will already have implemented abatement techniques or introduced lower emission technologies, while others have not done so. The EPER dataset does not provide information on the level of abatement already implemented at individual facilities.

When comparing the frequency distributions of implied emission factors with the emission factors corresponding to BAT as described in the LCP BREF, it can however be concluded that the full introduction of BAT (as described in the LCP BREF), could have decreased the emissions for these pollutants considerably in 2004 at EU-25 level. This is in line with the study results concerning the emission reduction potential for SO_2 and NO_x.

DISCUSSION AND CONCLUSIONS

This study shows that data collected at facility level within a pollutant release and transfer register (PRTR) does contain valuable information that can be used to assess the implementation of emission abatement policies. As in most PRTR's however, information on technical details and possibly installed abatement at the units and facilities is not available in the PRTR itself. Since such information is needed to evaluate the implementation of abatement and other technical measures, PRTR data must be complemented with additional data. Such data on large combustion units, operated in power plants, were found in the commercially available Platts power plants database.

Using this additional information, the fuel combusted at individual units within 450 individual power plants in Europe could be estimated from reported CO_2 emissions and the environmental performance of the plants could be assessed against what might be expected if Best Available Techniques would be implemented at these units.

The study shows that considerable reductions of emissions of NO_x and SO_2 at European power plants still can be achieved if all these plants would operate technical abatement options that would comply with the best available techniques.

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KEY WORDS

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