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The Costs and Health Benefits of Reducing Emissions from Power Stations in Europe

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The Costs and Health Benefits of Reducing Emissions from Power Stations in Europe

By Mark Barrett (UCL) and Mike Holland (EMRC).

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Authors

Mark Barrett, Principal RCUK Academic Research Fellow

Bartlett School of Graduate Studies

University College London, (Room 307), 51 Gordon Square, London WC1H 0PQ , UK

Email: Mark.Barrett@ucl.ac.uk

Site : www.bartlett.ucl.ac.uk/markbarrett/Index.html

Tel: +44 (0)20 7679 8656

Mike Holland, EMRC

2 New Buildings, Whitchurch Hill, Reading RG8 7PW, UK

Email: mike.holland@emrc.co.uk

Tel: +44 (0)118 984 3748

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1. Summary and conclusions

Current levels of emissions of sulphur dioxide (SO_2) and nitrogen oxides (NO_x) from power plants generate very significant health and environmental damage across Europe.

This study demonstrates that by applying up-to-date emission control technologies, these emissions could come down drastically. By estimating the costs and health benefits of further emission reductions, this study highlights the potential for substantial benefits for the European population from continued action to reduce emissions of SO_2 and NO_x.

Application of advanced emission control technologies to the 100 most polluting plants in the EU27 could reduce annual emissions of SO_2 and NO_x by approximately 3,400 and 1,100 kilotonnes respectively. This would cut total EU27 emissions of SO_2 by approximately 40 per cent and emissions of NO_x by 10 per cent.

The average benefit-to-cost ratio for measures at these 100 plants is 3.4, i.e. the estimated health benefits are 3.4 times bigger than the estimated emission control costs. The focus of this report on health means that damage to ecosystems and buildings is not included in the estimated benefits.

Emissions from large industrial point sources are currently regulated by the EU directives on Integrated Pollution Prevention and Control (IPPC) and Large Combustion Plants (LCP), and in December 2007 the European Commission presented proposed draft legislation to revise these directives.

It is evident from this study that there is significant variation in the application of emission control technologies between different plants and different countries. Improved application of Best Available Techniques (BAT) for reducing air pollutant emissions from large industrial point sources could contribute significantly to better air quality in Europe.

Methodology and main results

This study estimates the costs and health benefits of further reductions in emissions of sulphur dioxide and nitrogen oxides from power stations in Europe.

As part of the work, the SENCO database on large point sources of air pollutant emissions was updated. The database covers some 7,000 plants in countries throughout Europe, and in countries further east including Turkey and some former Soviet Union countries, including approximately 4,700 fossil-fuelled power plants, with a combined total generating capacity of 465 Gigawatts.

Emission data shows that a relatively small number of plants emit a large fraction of total pollution. The 100 biggest plants provide 40 per cent of the generating capacity and are responsible for approximately half of the SO_2 and NO_x emissions from all the power plants in the database. Similarly, the 500 biggest plants provide 85 per cent of the capacity, and around 90 per cent of the emissions.

The scope for further emission reductions was assessed by theoretically applying the best available emission control technologies (BATECT) to all the power stations in the database. Based on information that included an extensive literature review, it was estimated that applying BATECT would result in removal efficiencies for SO_2 of 98 per cent, and for NO_x of 90-94 per cent, at each power station.

Costs for emission controls were split between capital costs; operation and maintenance costs; fixed annual costs; and, variable costs. Account was taken of several factors, such as plant size and age, currently applied emission control technologies, and type of fuel used.

Tables are provided in which the 100 largest emitters of SO_2 and NOx, respectively, are listed for both EU27 and for Europe as a whole, including plant-by-plant data on estimates of the further emission removal potential and costs.

The analysis of emission abatement and associated costs indicate that application of advanced emission control technologies to the 100 most polluting plants in the EU27 could reduce annual emissions of SO_2 and NOx by approximately 3,400 and 1,100 kilotonnes respectively, at a total cost of about 6.9 billion euro, equalling an average cost of 1,500 euro per tonne of pollutant reduced.

By combining the Clean Air For Europe (CAFE) health assessment methodology with SENCO's emissions database for power plants, health-related damages linked with emission of NOx and SO_2 on a plant-by-plant basis were assessed.

Health impacts have been quantified principally against the sulphate and nitrate aerosols – so-called secondary particles that are formed in the atmosphere following the emissions of SO_2 and NOx. Effects of ozone formation linked to NOx emissions are also included, but these make a very small contribution to total damage estimates. Emissions of primary particles from power plants, which in some cases may be significant, were not included in the assessment.

The CAFE health assessment methodology applied monetary valuation of health impacts from air pollution that included both illness (morbidity) and death (mortality). For this report, the most conservative CAFE valuation of mortality, i.e. the lower estimate of 52,000 Euro as the value of a life year lost, was used for the benefits estimates. There is roughly a factor of four difference between results generated using this figure and those generated using the higher CAFE mortality valuation of the value of a statistical life, i.e. if the higher CAFE mortality valuation is instead used in this study, the resulting estimated benefits would be about four times higher.

The estimated costs and health benefits, as well as the benefit-to-cost ratio, for individual plants are presented in a table of the 100 power stations in the EU with the largest combined SO_2 and NOx baseline emissions. For the 100 plants listed, the average benefit-to-cost ratio is 3.4, i.e. the estimated health benefits are 3.4 times bigger than the estimated emission control costs. The focus of this report on health means that damage to ecosystems and buildings is not included in the estimated benefits.

When considering the results presented in the report, it is important to be aware of the uncertainties that are present. Not least of these is that some plants have changed emissions since 2004, the latest reporting year for the EPER database, either for operational reasons or in response to legislation. There are also uncertainties in the impact quantification methodology, relating to attribution of damage to specific types of particle (here, sulphate and nitrate aerosols), use of country-average damage estimates, etc.

Consequently, the overall conclusions in terms of total emissions and averages and ranges of emission control costs, etc. are more robust than information for individual power stations.

2. Introduction: Motive and policy context

Power plants that are fired with fossil fuels are big emitters of air pollutants, including sulphur dioxide, nitrogen oxides, fine particles, and heavy metals (e.g. mercury) – all damaging health and the environment. They all emit, too, large amounts of the greenhouse gas, carbon dioxide.

It is well known that a great part of these emissions comes from a relatively small number of point sources, primarily coal-fired power stations. This was shown in earlier studies made by Mark Barrett for the Swedish NGO Secretariat on Acid Rain, where it was estimated that between 75 and 90 per cent of the man-made emissions of sulphur dioxide in Europe came from a few thousand point sources, while the hundred worst ones were alone responsible for more than 40 per cent of the total.

Emissions from large point sources are regulated by EU legislation – primarily by Directive 1996/61 on Integrated Pollution Prevention and Control (IPPC), and Directive 2001/80 on the limitation of emissions of certain pollutants into the air from large combustion plants (LCP). The latter sets emission limit values for sulphur dioxide, nitrogen oxides, and dust from plants with a thermal input greater than 50 megawatts.

Moreover, limits for maximum total emissions of sulphur and nitrogen oxides for each EU member country are specified in Directive 2001/81 on national emission ceilings for certain atmospheric pollutants.

In its Thematic Strategy on Air Pollution from September 2005, the European Commission assessed that the long-term objectives for health and the environment – as established in the EU's Sixth Environmental Action Programme and in the National Emissions Ceilings directive – will not be attained on the basis of current policies by 2020. The Commission therefore in the strategy proposed a series of interim objectives to be attained by 2020, and several measures to promote progress towards meeting the long-term objectives.

In December 2007, a compromise agreement on the new air quality directive was reached. Here, a new limit value related to the fine particles ($PM_{2.5}$) which are especially harmful to peoples' health, is set at 25 micrograms per cubic meter ($\mu g/m^3$) to be achieved by 2015.

For comparison, the air quality guidelines agreed by the World Health Organisation (WHO) in October 2005 recommend an annual average $PM_{2.5}$ standard of 10 $\mu g/m^3$.

However, a provisional $PM_{2.5}$ limit of 20 $\mu g/m^3$ by 2020 was also agreed, subject to a "favourable assessment" by the European Commission in 2013. The assessment will cover experience gathered with the weaker limit, technical feasibility and the health and environment benefits of moving to the tougher target.

Analysis under the recent CAFE (Clean Air For Europe) programme of the European Commission highlighted substantial health impacts linked to air pollution. CAFE estimated a loss of 3.6 million life years in the year 2000 attributable to exposure to fine particles in the EU, a figure equivalent to around 350,000 premature deaths. A further 20,000 premature deaths per year were linked to ozone exposure. The CAFE analysis also estimated very significant numbers for cases of ill health linked to air pollution, ranging from lost work days to bronchitis and hospital admissions.

The application of Best Available Techniques (BAT) for reducing air pollutant emissions from large industrial point sources could contribute significantly to improved air quality.

Revision of the IPPC and LCP directives

In December 2007, the European Commission proposed draft legislation to further reduce emissions from thousands of industrial installations regulated under the IPPC and LCP directives.

In its communication (COM(2007) 843 final: *Towards an improved policy on industrial emissions*) the Commission estimates that a higher uptake of BAT by large combustion plants "would play a significant part in helping to close (by 30-70%) the existing gap" between the baseline projections for emissions of sulphur dioxide (SO_2) and nitrogen oxides (NOx) emissions in 2020 and the objectives set in the Thematic Strategy on Air Pollution.

Estimates by the Commission show that the additional emission reductions achieved at LCPs alone are likely to offer annual health benefits ranging from 9 to 30 billion Euro, including cutting the number of premature deaths from air pollution by 13,000 per year. These health benefits could be compared to annual costs of about 2.1 billion Euro, which means that benefits outweigh costs by up to 14 times.

The Commission's impact analysis also shows that by adopting a stricter interpretation of BAT-based emission limit values for LCPs, annual health benefits would rise to between 20 and 65 billion Euro, while yearly costs would increase to 6.5 billion Euro. The resulting net benefits – still without including ecosystem benefits – would consequently amount to 13-58 billion Euro per year.

Studies on large combustion plants' environmental performance (e.g. Barrett, 2004) show that there are a very large number of existing plants burning fossil fuel that easily meet the emission limit values set in the LCP directive for new post-2003 installations. There can therefore be no doubt as to the possibility of achieving emission levels, by the use of conventional technology, that are considerably lower than the current EU SO_2 and NOx standards for large combustion plants.

These studies show, too, that by far the greatest part of the emissions of SO_2 – about 90 per cent – comes from old plants (built before 1987). If the emission reductions that will be needed in the next five-ten years for the fulfillment of the EU aims for air quality and acidification are to be achieved, something must obviously be done about the emissions from these plants.

It is clear that many of the "worst" SO_2 and NOx emitters are significant point sources also for emissions of fine particulates and carbon dioxide. Consequently, there is a great potential for multiple benefits of smart emission abatement strategies, e.g. the introduction of strict technology forcing emission standards that are designed to promote both energy efficiency and a switching from the dirtiest fuels (e.g. coal) to cleaner, primarily renewable sources of energy.

The setting of strict mandatory emission limit values for existing plants would help ensure that the oldest, least efficient, and dirtiest plants would be shut down. And those that were to be kept going would either have to be retrofitted for modern flue-gas cleaning or fired with cleaner fuels, or both.

This study shows that the costs of applying efficient up-to-date emission control technologies to a large fraction of the fossil fuel-fired large combustion plants in Europe are significantly less than the economic benefits of improved health – even though the latter include health benefits solely related to secondary particles (from SO_2 and NOx emissions). These benefits would be further extended if other pollutants, such as mercury, were controlled with integrated flue gas treatment technologies.

Reductions in emissions of SO_2 and NOx would in addition bring a series of other benefits which are less easily quantified in monetary terms, including less damage to ecosystems and biodiversity trough acidification, eutrophication and ozone, and reduced rates of corrosion and weathering of buildings, materials and cultural monuments.

The proposed revision of the IPPC and LCP directives provides an opportunity to adjust and strengthen the emission limit values, and the results of this analysis should be taken into account when making policy for the future control of the emissions from large combustion plants in Europe.

April 2008

Christer Ågren

Director

The Swedish NGO Secretariat on Acid Rain

3. Overview

Large Point Source (LPS) combustion plants are major emitters of atmospheric emissions of nitrogen oxides (NOx), sulphur dioxide (SO_2), particulate matter (PM) and a range of other pollutants such as mercury that cause direct damage to human health and the biosphere. LPS are also a major source of carbon dioxide (CO_2), a major greenhouse gas.

The study assesses the scope for reducing these emissions by applying Emission Control Technologies (ECT) to LPS, where ECT are taken to include technologies for reducing the emission of pollutants by reducing the primary formation of pollution (e.g. by boiler modification), and by reducing the concentrations in flue gases (e.g. with Selective Catalytic Reduction, SCR). Other emission control measures, such as fuel switching or changing plant output, are not considered here.

In this study, LPS are restricted to power stations since these are generally the largest emitters and there are accessible comprehensive data on existing ECT for power stations, which are not available for other LPS such as refineries or smelters. The pollutants are covered by a range of regulation through EU Directives and international agreements which specify emission limits at plant and national levels. The emission reductions and costs of applying Best Available Techniques (BAT) in the form of ECT are assessed – BATECT.

The results of the analysis are presented in tables and graphs, that show the potential for the application of BATECT in the regions studied.

The study contributes towards the development of emission control policies and the associated markets for emission control technologies, especially in the newer EU Member States, and countries further to the east such as Ukraine and Turkey where the scope for additional control is greater. The study sets up a framework that can be applied to any country as it uses global databases. This would be of use for looking at emission control policies and ECT markets in other countries and regions, such as China or India.

In the second half of the study, the emissions data from the LPS are used to assess health impacts and costs. The LPS emissions are input to the a model for estimating health costs based on the methodology and assumptions used for the benefits assessment of the Clean Air For Europe (CAFE) Programme. The analysis allows comparison of the costs of abatement and the reduction in health damage.

The ambitious scope of this work, covering several thousand installations, means that information for particular power stations may be inaccurate. The overall conclusions in terms of total and average emissions, etc. are, however, more robust than the results for individual power stations.

3.1. Programme of work

The following tasks were undertaken by Barrett of UCL.

1. Obtain most recent data by updating the EPER, Platts, IEA energy, and EMEP databases as available.
2. Collate and normalise the databases, and identify and resolve discrepancies.

3. Collate data on costs and reductions of different Emission Control Technologies.

4. Determine current application of ECT from the primary databases.

5. Calculate current emissions accounting for reductions in primary emissions of SO_2, NOx and PM due to existing ECT.

6. Write programme to calculate costs of additional emission reductions of current plants to BATECT standards.

7. Calculate the costs and emission reductions of applying BATECT.

The results of this work were then utilised by Holland of EMRC to estimate health impacts and costs, using damage factors per tonne of pollutant that had been quantified previously in work for the European Commission under the CAFE (Clean Air For Europe) Programme (Holland et al, 2005). The methods that underpin these damage factors were developed following extensive debate with the CAFE stakeholders and were subject to independent peer review (Krupnick et al, 2004). The reduction in monetised health damages arising from the adoption of BATECT standards was then compared with the costs for the cost-benefit analysis.

4. Emission control technologies

Pollution from fossil and biomass combustion for energy production may be reduced through a number of measures:

- lowering energy demand with energy efficiency;
- using non-combustion energy sources, e.g. wind turbines;
- improving combustion and overall efficiency , e.g. with Combined Heat and Power;
- switching to cleaner fuels, e.g. from coal to gas;
- improving fuel quality, e.g. reducing the sulphur content of coal or oil;
- using Emission Control Technologies (ECT) during and after combustion.

This study will solely consider the last option – ECT applied during combustion (called primary processes); and processes applied to the flue gases after combustion. Primary and flue gas treatment processes may often be combined to achieve a lower overall cost per tonne of emission reduction. It is fairly common for combinations to be used to control NOx: a primary process, such as boiler firing modification, may be combined with flue gas treatment. Most ECT control increases CO_2 per station output because energy is required to run emission control equipment, and there may be other efficiency losses.

There are a number of processes used for the prevention and removal of SO_2, NOx and PM separately. Some processes will influence the emissions of more than one pollutant; for example, Flue Gas Desulphurisation (FGD) will remove some NOx and PM, as well as SO_2. Of particular note, is that mercury emissions are of increasing concern and that FGD can be modified to remove a significant fraction of this metal.

A comprehensive summary of emission control is to be found in *Integrated Pollution Prevention and Control Reference Document on Best Available Techniques for Large Combustion Plants* (European Commission, 2006); this is given the acronym LCPBREF in this document.

4.1. Best Available Technique (BAT)

The concept of Best Available Technique (BAT) is primarily associated with the EU Integrated Pollution Prevention and Control Directive (IPPC). It is not a precise concept because it involves a mix of technical, economic and environmental considerations which can vary across different industrial applications and across time. The integrated approach required by IPPC means that account must be taken of all emissions to all environmental media.

Therefore, although it is possible to remove almost 100% of pollutants such as SO_2 and NOx from flue gases, account must be taken of the fact that as the percentage removal increases the marginal size, efficiency losses (and CO_2 emissions) and costs of the ECT installation increase faster than the removal improvement; increasing removal from 85 to 90 per cent is less costly than increasing it from 90 to 95 per cent. In general, the higher the gas concentration of a chemical pollutant (NOx, SO_2), the greater a fraction that may be removed for a given technology.

SCR can achieve high reduction efficiencies (>70%) on NOx concentrations as low as 20 parts per million (ppm). Higher NOx levels result in increased performance; however above 150 ppm, the reaction rate does not increase significantly.

USEPA, 2003a

As pollutant emissions are further reduced, there comes a point – at least in theory – at which the cost and performance penalty is so large that:

1. It becomes much more difficult to meet carbon dioxide emission limits because of energy efficiency losses;
2. The energy performance penalty of the ECT at one plant is such that overall emissions will rise because more fuel has to be burned at that plant or elsewhere to achieve a given level of electricity output;
3. Options such as demand reduction or alternative low or zero emission generating technologies like wind turbines become more attractive options for emission control.

Apart from this performance penalty, BAT is partially defined by the balance of environmental benefits and economic costs it brings. However, within IPPC there is a requirement to go beyond BAT where an assessment of 'reasonable costs' would result in a breach of a local environmental quality standard. A particularly good example lies outside the EU and IPPC: the application of Selective Catalytic Reduction (SCR) to gas-fired plants is common in California because gas-fired plants are, in some instances, major causes of non-compliance with Local Air Quality Standards (LAQS), and SCR is sometimes one low or least cost step to compliance.

In implementing IPPC BAT at the local level, regulators are guided by a series of BAT Reference Documents (BREFs) which set out benchmark BAT standards for the particular industrial sector or cross-sectoral issue. Currently, in the LCP BREF, SCR is not benchmark BAT for gas-fired plants unless specifically required by the local air quality standards because the magnitude of NOx emissions from gas-fired plants and resulting abatement mean that the costs of SCR are generally not considered justified. Despite this, SCR has been applied to some gas plants in Europe.

Bregani et al (2002) report on Italy's SCR capacity:

More than 13,000 MW_e of Italian power generation capacity have been retrofitted by SCR technology since middle '90s. SCR denoxing reactors are in operation on all large coal and orimulsion fired power plants. Many oil and gas fired power plants have been equipped with SCR technology too, even if their use depends on performances of primary technologies. Enel Produzione Spa, the largest Italian utility, has 22 fossil fired units (from 240 to 660 MW each) equipped with SCR.

Of the plants Bregnani et al list, 4,560 MW_e of the plants with SCR technology are natural gas fired, and 2,640 MW_e oil fired.

In Germany, SCR has been applied to a range of fossil plants. According to Hartenstein and Gutberlet (1999):

Two German environmental resolutions (GFAVO of June, 1983 and UMK of April, 1984) enhanced the adaption of the SCR technique in German power plants. From the end of 1984 to 1987 most German utility owners ran pilot plants in order to become acquainted with this technology and to determine whether there are special deterioration mechanisms. The first full scale plants started operation at the end of 1985. Since then, around 120 SCR plants have been installed on utility coal, oil and gas fired power plants. The application *of SCR technology for NOx control has also been made on waste-to-energy plants, sintering plants, wood fired boilers, chemical plants, sewage sludge incinerators, and cement plants.*

The IEA Clean Coal Centre (2007a) comments:

SCR technology has been used commercially in Japan since 1980 and in Germany since 1986 on power stations burning mainly low-sulphur coal and in some cases medium-sulphur coal. There are now about 15 GW_e of coal-fired SCR capacity in Japan and nearly 30 GW_e in Germany, out of a total of about 53 GW_e worldwide.

A key question is whether a technology such as SCR is regarded to be cost-effective now or in the future to apply to gas (or other) plants in order to meet European environmental targets such as local air quality standards or National Emission Ceilings (NECs).

For example, some countries may find it hard to meet NECs for NOx for 2010, and possibly for targets further in the future. The cost of removing NOx with SCR on gas plant has to be compared with the costs and potentials of controlling emissions from other sources such as vehicles. The scope for individual action by Member States is limited for some sources, such as vehicles where technology emissions standards are applied EU wide. Further considerations include the rate at which ECTs can be implemented in the different sectors. These factors may make SCR applied to gas fired power stations, for example, the best marginal option in terms of Euros per tonne of emission reduction, or the total cost of meeting some target.

A comprehensive analysis of this complex issue has, to the authors' knowledge, not been carried out and is beyond the scope of this study. An integrated assessment of energy systems and their environmental impacts is needed to discover whether in a particular situation that, for example, applying SCR to a gas-fired plant is the least cost option to meet environmental targets.

The approach taken in this study differs from IPPC in two respects. Firstly, IPPC BAT standards for technologies are set as emission values, e.g. mg/Nm^3. In this way, IPPC takes account of both the abatement potential of the emission control technology and the characteristics of the fuel. In this study, the fuel quality is taken to be a constant to which the removal efficiency of the emission control technology is applied. Information on typical removal efficiencies is contained in the LCP BREF.

Then, secondly, in the BREF, the BAT standards and removal efficiencies are presented as a range of values that are judged to be benchmark BAT. By contrast, this study focuses on the maximum removal efficiency, and to differentiate it from IPPC BAT, this is called BATECT – BAT maximum emission control technology.

This is applied to all power stations and cost curves (Euro/tonne abated) are derived for a whole region. This requires the collation of data on the emission control performance and costs of BATECT. These performance and cost data for BATECT have been drawn from a number of sources. These demonstrate that the BATECT most appropriate for a plant, and its performance and costs, depend on many factors such as are shown in Table 1.

System capital costs for retrofit applications removing between 60 and 90 % NOx range between €50/kW and €100/kW, where the costs for larger plants are at the lower end of this range and the costs for smaller plants at the higher end. The main factors contributing to full retrofit costs for SCR systems on coal plants with a target NOx emission level of 185 mg/Nm^3 are unit size, inlet NOx concentrations and the varying construction needs associated with the level of retrofit difficulty. For instance, an increase in baseline inlet NOx concentration from 615 mg/Nm^3 to 1230 mg/Nm^3 will increase the SCR capital costs by around 50%. As unit size decreases from 1000 MW_e to 200 MW_e, the initial SCR capital *cost can decrease by up to 30%. The scope of retrofit determined fan upgrades, duct work, structural steel and foundation changes can impact costs by around 20 to 35 %. Operating costs for the reducing agent are approximately €75 per tonne NOx for anhydrous ammonia or €125 per tonne of NOx for a 40 % urea solution. Overall costs, i.e. investment and operating costs, for NOx reduction in an 800 MW power plant using an SCR range between €1500 and €2500 per tonne of NOx reduced [167, Rigby, et al., 2001].*

LPCBREF, p. 112

Certain authors have developed calculation programmes that account for at least some of these factors: e.g. Cofala & Syri (1998a, 1998b), Foerter & Jozewicz (2001). One of the more sophisticated programmes is the Coal Utility Environmental Cost (CUE-Cost) programme of the US EPA (1999) which is an interrelated set of spreadsheets that modestly claims to produce 'rough order of magnitude' cost estimates (+/-30% accuracy) of the installed capital and annualized operating costs for air pollution control systems installed on coal-fired power plants to control emissions of sulphur dioxide, nitrogen oxides, and particulate matter. It has been beyond the scope of this work to emulate such programmes because the necessary details of the power stations are not in the databases.

In a particular plant, combinations of techniques may be less costly and have a lower efficiency penalty than single technologies: such as combining 50% removal with low-NOx combustion and 90% removal with SCR flue gas treatment to give 95% removal overall, rather than 95% removal with SCR flue gas treatment alone.

Fiveland and Mohn (2006) of the company Alstom, summarise the Air Pollution Control Equipment Capability for coal plants as follows.

Today's state-of-the-art

SO_2 >99% capture with Wet FGD and DBA

NOx >95% reduction with SCR

Particulates ~ 99.99% capture

Hg 80-95% capture (coal dependent)

Table 1. Factors affecting applicability, costs and performance of BATECT.

Plant	plant size (MW_e/MW_{th}) plant technologies (fuel preparation, boilers, etc.) site and plant internal/external layout and characteristics whether ECT is for a new plant, or retrofitted pre-existing ECT such as low-NOx boilers or FGD the anticipated remaining plant life the exhaust gas concentrations of SO_2, NOx, metals, etc. prior to control
Fuel	fuel characteristics (coal, oil, gas, sulphur, nitrogen, ash, mercury, etc.)
Operation	the operating regime of the plant: annual capacity factor (average output / maximum output); plant cycling the effect of ECT on plant energy efficiency including the requirement for power to run ECT
Inputs	costs of materials for pollution removal (limestone, catalysts etc)
Outputs	markets for by-products (e.g. gypsum, sulphuric acid) waste disposal
Other	local environmental considerations

Alstom is a supplier of ECT and so these estimates may be at the high end.

4.2. BATECT

This section summarise assumptions for BATECT performance and retrofit costs. These data are distillations of information from a number of sources as set out in Annex 1.

The control of pollutants other than SO_2 and NOx are of interest, but are not covered in this report. Particulate emission has been controlled for many decades in Europe. In the USA and now Europe there is increasing concern to control the release of mercury. Integrated air pollution control systems are being developed that reduce the emissions of mercury as well as the other pollutants and thereby aim to reduce the total costs of control.

Fiveland & Mohn (2006) report on integrated air pollution control systems that use readily available reagents, produce reusable by-products and have 'targeted' emissions reduction levels of SO_2 (>99.5%), mercury (>90% on all coals), particulates (>99.99%) and NOx (>95%). Cinergy (2004) describe systems with integrated SCR, FGD and 80-85% mercury reduction.

4.2.1. Pollution removal

BATECT for SO_2

FGD (wet scrubbers) can remove more than 99% of SO_2 (IEACCC, 2006; Fiveland & Mohn, 2006). BATECT is taken here to be 98%. This is at the top of the LCPBREF range of 92-98%. IIASA assumes 90% for retrofitted plants, 95% for new plants and 98% for high efficiency FGD.

BATECT for NOx

Primary NOx control measures reduce the formation of NOx during combustion and include technologies such as low NOx burners (LNB) and over-fire air (OFA). In conventional coal and oil boilers these typically reduce primary NOx formation and emission by 30 to 70 per cent.

NOx can be further reduced by removal from exhaust gases after combustion. Currently SCR is applied to exhaust gases after combustion and removal efficiencies can reach 95% and more; see for example, Foerter (2001) and Fiveland & Mohn (2006). Cormetech (2001) reports a guarantee of 93% NOx removal with a retrofit SCR system applied to the New Madrid coal power station with 2 x 600 MW boilers. Babcock (2006) describes increasing the removal rate of a SCR installation from a design level of 85 to 93 per cent.

Primary measures and SCR can be applied to power stations with boilers – most large coal and oil power stations. Overall, a BAT efficiency of 94% NOx removal by combining primary and SCR measures is assumed for coal fired power stations. This is the result of a combination of measures: for example, of primary control with Low NOx burners (LNB) and overfire air (OFA) removing 55% and SCR removing 87% of the remainder.

4.2.2. Costs

The costs of BATECT may be divided into capital, operation and maintenance fixed annual and output variable. All of these costs vary widely with the factors outlined above. Note that costs here are given by thermal rating (kW_{th}) as it is the thermal output that fundamentally determines the amount of fuel combusted and the resulting exhaust gases.

The costs per electrical capacity and output can be found by dividing the thermal (kW_{th}) values by the efficiency of the power station (~38% coal; ~45% gas); a coal FGD capital cost of 100 Euro/kWh would be about 300 Euro/kW_e electrical capacity.

- Capital. This cost is in Euro/kW_{th}
- Operation and maintenance
- Fixed annual costs. These relate to the installed capacity of the ECT and are expressed in Euro/kW_{th}/a.
- Variable costs. These costs are proportional to the throughput of the ECT and include the costs of materials and reagents; this cost component is expressed in Euro/kWh_{th}. In this study it is assumed that all of a plants' output and associated pollution emissions are treated with ECT. However, sometimes the ECT is not operating when the station is generating: for example; the ECT might just be used in summer periods when NOx emission might lead to ozone exceedance.

Commercial confidence means there is a limited amount of public data on the actual costs and performance of ECT. Rubin et al (2004) demonstrate how the capital costs of FGD and SCR have declined with learning from experience historically. This does not account for the improved removal rates of more recent ECT which would further reduce capital costs per tonne of pollutant removed. Historical costs may not be a very good guide to future costs because in general ECT will first be applied to plant where the emission reduction unit costs are cheapest (Euro per tonne emission removed), and the plants currently without ECT have features that will increase costs over those incurred historically. For the USA, Marchetti and Cichanowicz (2007) opine (p.11):

> *It is widely believed that the first 100,000 MW of FGD capacity retrofit were installed on those units that provided the lowest removal cost ($ per tonne basis), which implies the least capital cost. The units remaining may present more challenging site conditions for retrofits.*

4.2.3. Summary

The features of ECT mean that the BAT emission reductions and costs presented here are approximate, and the results for a particular plant are unlikely to be very accurate, though the average reductions and costs over the whole stock of plant will be more reliable. Assumed typical figures are summarised in Table 2, which shows the assumed performance and costs of retrofitted BATECT SO_2 and NOx control for a large plant (>500 MW_e or 1500 MW_{th}). Note that efficiency loss is as a percentage increase in energy input required to produce the same output.

Figure 1 shows how the capital costs of retrofitted BAT SO_2 and BAT NOx control are assumed to vary with the thermal capacity (MW_{th}) of the power station. It is assumed that unit capital costs decline with thermal capacity (MW_{th}) because of scale economies, as analysts such as Amar (2003) indicate. However, note that Marchetti and Cichanowicz (2007) indicate that SCR unit costs may increase for very large plants.

As the percentage of flue gas pollutant removed is increased, so do the costs per tonne removed (Amar, 2003). For example, Vijay et al (2006) show NOx abatement costs to increase approximately linearly from $500/tonne for 10% NOx reduction removal to about $2500/tonne for 85%, before rapidly increasing to about $4500/tonne for 95%. Figure 2 illustrates this cost trend.

4.3. BATECT application to power stations

The objective is to estimate the extra emissions reductions and extra costs of applying BATECT. Many plant already have ECT, so the question arises as to what the additional emission reductions and costs of applying BATECT will be.

In general, the electrical capacity (MW_e) of a power station is given in the databases, and this has to be converted to MW_{th} by dividing by the fuel to electricity efficiency. The emissions reductions are simply the pre-existing emissions minus the emissions once BATECT is applied.

The additional avoidable costs of additional emission reduction with BATECT depend on the remaining life of any existing ECT. The two extremes are exemplified:

- an FGD system with 90% SO_2 removal is at the end of its life; then the avoidable cost of BATECT to increase reduction to 98% from 90% is the extra cost of a 98% system as compared to a 90% system.
- If the existing 90% FGD system is new, then the extra cost of BATECT is the whole cost of the 98% system.

An existing ECT may be entirely replaced because it cannot, for technical, reasons be upgraded to achieve BAT control levels; for example an existing dry sorbent FGD system with a maximum SO_2 removal rate of (say) 80% would have to be replaced with a new wet FGD system to achieve 98% removal. In some cases, an existing ECT can be upgraded or augmented to achieve BAT reductions; for example:

- a station might have low-NOx boiler ECT, and adding SCR flue gas treatment is an independent addition;
- the SO_2 removal rate of an FGD system might be increased by using extra or different absorbents.

To avoid such complexities, the approach taken here is to assume that no plant are replaced prematurely. The extra costs are those to take the plant from the existing pollution removal rates (0% if no ECT is applied already) to BAT removal rates. Operational costs are assumed to be those for BATECT.

The question then is: how long will the BATECT operate for? ECT plant have technical lives of 20 or 30 years and it may be assumed that in general ECT will operate as long as an existing power station does. The remaining lifetime of a power station depends on the future energy context, its age and economic, environmental and technical factors. In general, environmental constraints and fuel supply considerations reduce the competitiveness of fossil generation as compared to renewables and nuclear. However, to thoroughly assess the effect of these factors on the future lifetimes of fossil plant is beyond the scope of this work. Table 3 shows the effect of different assumed lifetimes

Table 2. SO_2 and NOx BATECT performance and costs.

Pollutant	Fuel	Tech.	Reduction	Effic. loss	Capital €/kW_{th}	O&M costs €/kW_{th}/a	O&M costs c€/kWh_{th}
SO_2	Oil	FGD	98%	2.5%	90	2.00	1.00
	Coal	FGD	98%	2.5%	100	2.00	1.00
NOx	Gas	SCR	90%	0.5%	20	1.50	0.50
	Oil	Boil.+SCR	92%	0.5%	20	1.65	0.55
	Coal	Boil.+SCR	94%	0.5%	60	1.80	0.60

Figure 1. SO_2 and NOx control capital costs of BATECT.

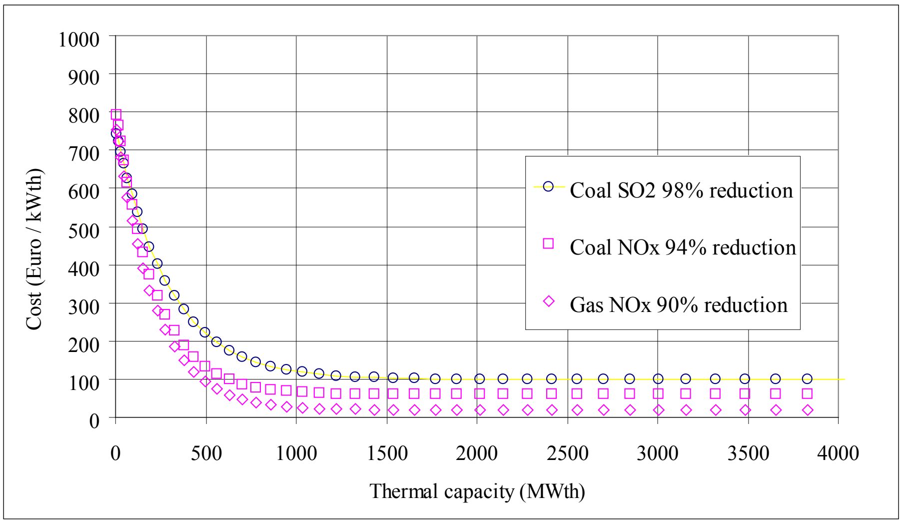
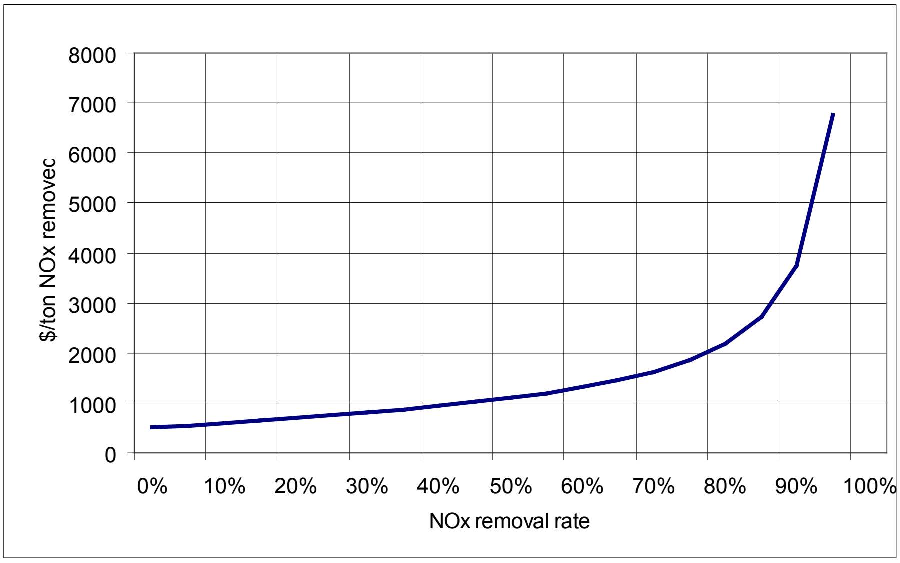


Figure 2. Increase of NOx control cost with removal rate.



and discount rates on the annuitised capital payment expressed as a percentage of the initial capital (shown in bold).

The capital cost of the BATECT is annuitised assuming a life of 15 years and an interest rate of 4%, to give a annual capital payment of 9%.

The calculation procedure for emissions is as follows:

- Take the base reported (EPER) or calculated emission (kt): Emit_kt.
- Evaluate the current removal rate, ECTRem_pc (%). This is the pollution emission reduction due to existing controls, and, for SO_2 only, the removal due to sulphur absorption in ash.
- Calculate primary emission without any removal (kt): PrimaryEmit_kt=Emit_kt/(1 - ECTRem_pc)

Table 3. The effects of ECT lifetime and discount rates.

Discount rate	ECT lifetime		
	10 years	15 years	20 years
4%	**12%**	**9%**	**7%**
10%	**16%**	**13%**	**12%**

- Evaluate BATECT removal rate ECTBATRem_pc from BATECT database.
- Calculate the addition removal rate (%): ECTBATExtraRem_pc = ECTBATRem_pc - ECTRem_pc
- Calculate the addition removal mass (kt): ECTBATExtraRem_kt = PrimaryEmit_kt * ECTBATExtraRem_pc

The calculation procedure for costs is as follows:

- Estimate heat input rating (MW_{th}) from given capacity (MW_e) and the assumed efficiency: $CapMW_{th}$ = CapMWe / Efficiency
- Evaluate the capital costs for plant capacity, and operational costs from BATECT data and cost functions (Euro).
- Calculate the total annuitized costs for the plant (Euro/a).
- Calculate the cost per extra emission removed, the abatement cost (Euro/t).

Note that the BATECT abatement costs depend critically on many variables relating to the fuel, the plant and the plant performance. Table 4 shows the calculation method applied to a 1.5 GW_e coal station.

4.4. Limitations of analysis

There are two principal limitations to the ECT side of the analysis; the basic databases have a number of drawbacks, and there is no modelling of wider effects on electricity systems.

4.4.1. The databases

The LPS combined database has been updated using the 2004 EPER data, and Platts 2007 (Platts, 2007) power station data. In this study, only power station data are used since the author has no data on the emissions controls for other plants such as refineries; the power station database is called LPSPower. The IEA Clean Coal Centre (IEACCC) produce a database with details of coal-fired power plants worldwide called CoalPower (IEACCC 2007b). Unfortunately it was not possible to utilise the more recent IEACCC Coal Power 5 because permission was not granted to transfer the whole dataset into a single database for processing.

There is particular difficulty in matching records in one database with those in another. The reader is referred to Barrett (2004) for a detailed discussion of the problems combining the primary EPER, Platts, and IEACCC databases. Problems include:

- Some plant may simply be missing from a database.
- Different names, spellings or alphabets are used for the same plant.
- What may be regarded as a single plant in one database, may be several in another because of different names, stacks, fuels, construction date, etc.
- Data are for different years: EPER data are for 2004, Platts 2007 and IEACCC for 2000.
- Plant recorded in one database may not be recorded in another because the plant is new, retired, did not operate in the latest EPER data year, etc.
- Some plants can use several different fuels (e.g. coal, oil, gas) each with different sulphur and nitrogen characteristics.
- Emission control equipment is sometimes not recorded properly or at all in the power station databases.

Table 4. Coal station sample calculation.

Station				
Capacity	Electrical	GW_e	1.5	
	Thermal	GW_{th}	4.0	
Output	Capacity factor	%	70%	
	Electricity	TWh	9	
Input	Heat input	PJ	89	
	Heat input	TWh_{th}	25	
Coal	Calorific value	GJ/t	26	
	Input	Mt	3.4	
	Sulphur	%	1.7%	
	Sulphur	kt	58	
	Sulphur retention in ash	%	5.0%	
Emission			SO_2	NOx
	Base emission	kt	110	44
	BAT removal	%	98%	94%
	BAT emission	kt	2	3
	Emission reduction	kt	108	42
Abatement costs				
Capital		$Euro/kW_{th}$	100	60
		MEuro	403	242
	per year	MEuro/a	39	23
	per tonne	Euro/t	361	562
O&M	Fixed	$Euro/kW_{th}/a$	2.0	1.8
	per year	MEuro/a	8.1	7.3
	per tonne	Euro/t	74	173
	Variable	$cEuro/kWh_{th}$	1.0	0.6
	per year	MEuro/a	25	15
	per tonne	Euro/t	228	355
	Total O&M	Euro/t	303	528
TOTAL	per tonne	Euro/t	664	1090
	per kWh	cEuro/kWh	0.07	0.12
Total	per kWh	cEuro/kWh	0.20	

Because of the size of the various databases, from 2,000 to 15,000 records, a computer programme was written to automate the record matching process. However, the programme inevitably provides imperfect results and so extensive manual checking was still needed, though it is not possible to be exhaustive because of the database size; in any case the basic information often does not allow accurate checks with a programme or manually. Because of this, there remain many mismatched and unmatched records in LPSPower.

The data problems mean there are strong reservations about individual station results; particularly because the BATECT abatement costs depend critically on many variables relating to the fuel, the plant and the plant performance. Of especial note is that the EPER emissions data and fuel consumption and base ECT data from the IEACCC database are for different years, and this substantially changes results for individual stations. A constant capacity factor could have been used for all stations as a basis for calculations, but this would not be realistic and would distort the overall results in terms of costs.

The problems of information in databases being inadequate for detailed analysis of emissions and emissions control, and of reconciling information between databases have been discussed in more detail here and previous reports (Barrett, 2004). Suggestions as to how matters might be improved have also been made. The only satisfactory resolution of these problems is to define precise conventions for names, stack allocation, etc. prior to the collection of the data and to incorporate the appropriate fields in the primary databases. A major advance would be if power stations in the Platts and IEACCC power station databases were linked by common names, or other codes, to EPER.

4.4.2. The system effects of ECT

In general, ECTs reduce the net efficiency of energy conversion in technologies (power stations, vehicles, etc.). This is either because energy is required to run ECT, such as for preparing and pumping limestone slurry in an FGD plant, or because the primary energy conversion process itself is made more inefficient – e.g. reducing NOx in boilers by changing combustion conditions can reduce efficiency. As a result, ECT usually increases fuel consumption per output (kWh) of a plant, resulting in higher CO_2 emissions per output.

Any electricity required to run ECT (e.g. FGD or SCR) on a power station reduces its net output to the grid and consumers. This loss of electricity has to be made up with extra generation by other plant and, if they are fossil plant, this engenders increased emission of CO_2, and indeed other pollutants at those plant, which may be less efficient than the plant with ECT. Similarly, extra capital and running costs will actually be incurred in these other plants.

In addition, there are other energy and emission impacts caused by running ECT; for example through the mining, transport and disposal of materials for running FGD.

It is beyond the scope of this study to properly account for such system effects. As a first approximation, therefore, it is assumed that the extra emissions (CO_2, SO_2, NOx) and costs incurred by the use of energy in ECT are 2.5% for those plants to which SO_2 and NOx BATECT is applied (coal and heavy oil plant), and 0.5% for NOx BATECT only (gas plant). This approach may well overestimate the system wide emission reductions of ECT and underestimate the costs though the error is likely to be small, probably less than 5%.

5. Results

This section gives the results of applying BATECT to the power stations of Europe and western Asia in the database that use combustible fuels, the majority being fossil fuelled rather than fuels such as biomass or municipal waste. Results for all these stations are labelled 'All', and those for the EU27 are labelled 'EU27'.

Descriptions of the legends and headers used in the Figures and listings of individual power stations are shown in Table 5.

In the listings of individual power stations, this formatting has been applied to each power station row:

- **bold** signifies power stations with matched EPER (2004) emissions, but matching may be incorrect;
- *italic* signifies power stations which should have EPER emissions but no match was found because of matching error or because there is no entry in the EPER.
- Standard formatting is applied to power stations in countries not included in the EPER 2004 data collection.

5.1. Power stations

Some 4,700 fossil fuelled power stations are in the database, ranging from large remote power stations with a capacity of several GW, to small generators of about a MW

Table 5. Legends and headers.

Acronym	Description
Figure legend	
CapEleNet_MW	capacity of each power station (MW_e)
CapEleNetCum_GW	cumulative capacity of stations (GW_e)
SO2BaseCum_kt	cumulative base SO_2 emission (kt)
SO2BATCum_kt	cumulative post-BAT SO_2 emission (kt)
SO2 _ExtraRedCum_kt	cumulative extra SO_2 reduction due to BAT (kt)
NOxBaseCum_kt	cumulative base NOx emission (kt)
NOxBATCum_kt	cumulative post-BAT NOx emission (kt)
NOx_ExtraRedCum_kt	cumulative extra NOx reduction due to BAT (kt)
ECTExtraSO2NOxTotalCost_Europtonne	extra cost of SO_2+NOx removal (Euro/t)
ECTExtraTotalCost_cEuropkWhe	extra cost of BATECT (cEuro/kWh_e)
ECTExtraSO2TotalCost_Europtonne	extra cost of BATECT SO_2 removal (Euro/t)
ECTExtraNOxTotalCost_Europtonne	extra cost of BATECT NOx removal (Euro/t)
Table header	
Cou	country
Plant	plant name
MW_e	capacity
Base kt	emissions before BATECT
ECT	emission control technology before BATECT
Rem%	emission reduction before BATECT
BAT Red kt	extra emission reduction with BATECT
Emit post BAT kt	emissions after BATECT
Euro/t	emission abatement cost per tonne

mostly installed in industrial and service sector facilities. Altogether, a total capacity of 465 GW_e is included in the database. Figure 3 shows the capacity of the 3,000 largest individual power stations, ordered by decreasing individual capacity in MW_e, and the cumulative capacity.

The same plants are shown with cumulative capacity and current emissions of NOx and SO_2 in Figure 4.

These graphs demonstrate how a small number of plants account for the bulk of capacity and emissions. Table 6 summarises this: the largest 50 account for 25-30% of capacity and emissions, the largest 100 for 40-50%.

5.2. Emissions: EU27

Table 7 summarises the total power station emissions of SO_2, NOx and CO_2 from EU27 power plants in the database. Alongside these are set national emissions reported to the Convention on Long-Range Transboundary Air Pollution (LRTAP Convention)

Figure 3. All plant: capacity (GW_e) and station size (MW_e).

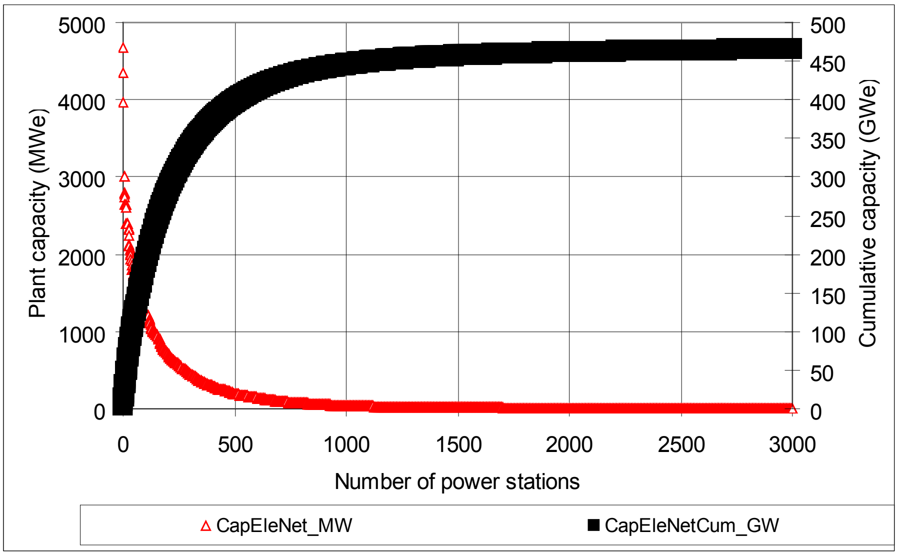


Figure 4. All plant: cumulative capacity (GW_e) and emissions (kt).

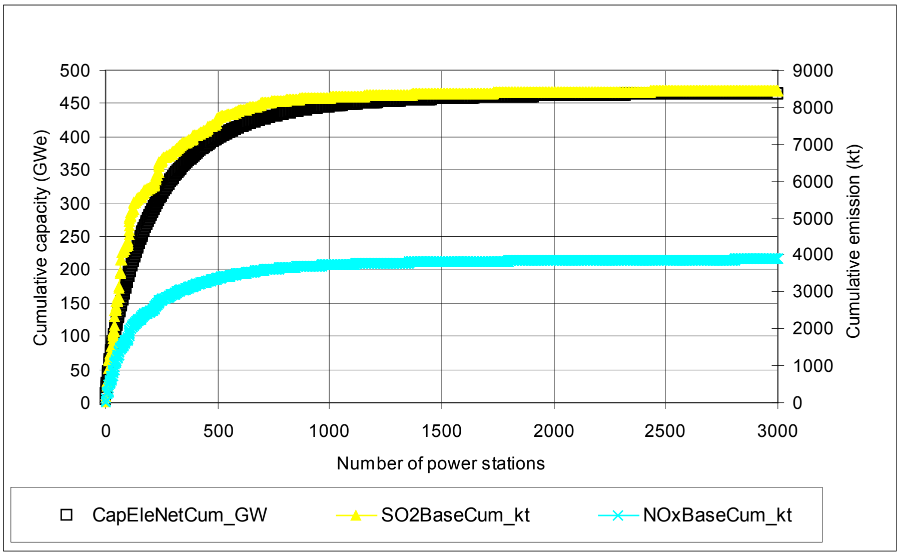


Table 6. Summary of statistics for all power stations.

Number		Cumulative capacity		Sulphur dioxide		Nitrogen oxides	
N	%	GW	% Total	kt	% Total	kt	% Total
50	1%	115	25%	2,724	32%	1,179	30%
100	2%	184	40%	4,300	51%	1,726	44%
500	11%	397	85%	7,690	91%	3,373	87%
750	17%	431	93%	8,144	96%	3,623	93%
1000	22%	445	96%	8,256	98%	3,726	96%
3000	67%	465	100%	8,435	100%	3,881	100%

Table 7. Comparison between LPS Power database and nationally reported emissions (ktonnes).

	LPS Power database			LRTAP 2004		LRTAP/LPS Power	
	CO_2	SO_2	NOx	SO_2	NOx	SO_2	NOx
AUT	12,027	10	11	4	11	39%	105%
BEL	26,434	41	41	34	35	82%	85%
BGR	22,292	587	119	782	55	133%	47%
CYP	3,910	34	9	31	7	92%	71%
CZE	47,605	78	102	124	93	160%	91%
DEU	365,654	234	312	235	223	101%	72%
DNK	26,918	14	44	10	44	72%	100%
ESP	105,860	954	329	947	324	99%	98%
EST	8,704	48	9	73	14	151%	162%
FIN	34,364	71	66	40	49	57%	75%
FRA	38,142	138	122	113	105	82%	86%
GBR	214,706	566	424	496	350	88%	82%
GRC	64,752	489	171	379	85	78%	50%
HUN	14,471	109	21	126	28	115%	133%
IRL	15,801	53	36	44	32	83%	90%
ITA	160,644	236	172	174	111	74%	65%
LTU	537	8	3	-	-	-	-
LUX	1,106	0	1	-	-	-	-
LVA	1,227	0	3	1	6	311%	246%
MLT	2,000	17	5	12	6	68%	107%
NLD	19,779	4	31	14	51	352%	168%
POL	132,308	675	243	665	246	99%	102%
PRT	21,958	106	67	102	50	96%	74%
ROM	22,993	300	82	-	-	-	-
SVK	15	47	12	53	16	112%	134%
SVN	6,438	41	13	46	17	112%	127%
SWE	8,159	29	20	9	12	31%	61%
TOTAL	1,378,803	4,888	2,467	4,514	1,970	92%	80%

for the sector code 1A1a Public Electricity and Heat Production.General problems comparing the LRTAP and LPS power station database results are the classification (LPS-Power includes private power stations but not heat only plant) and general problems with different data years and omissions or errors in either database. For the whole EU27 the match in total emissions between LRTAP and the UCL database is quite close, especially if Romanian emissions were included in LRTAP. However, there are significant discrepancies for particular countries. This is especially for small countries where one large plant can make a significant contribution to a country total.

[The CLRTAP_NFR02_V6 database was downloaded on 18.09.07 from http://dataservice.eea.europa.eu/download.asp?id=17027&filetype=.zip]

Figure 5 shows the cumulative emissions of the sum of SO_2 and NOx before and after applying BATECT, plotted against the cumulative electrical capacity of the power stations to which it is applied. The power stations were ordered by increasing total cost per tonne of reducing the sum of SO_2 and NOx emission.

BATECT adds to the production costs of electricity, and these may be expressed as additional costs per kWh. Figure 6 shows the base and BAT emissions of SO_2 and NOx and the additional cost in Euro cents/kWh.

5.3. Sulphur dioxide: EU27

Figure 7 shows how the SO_2 removal costs (Euro/tonne) vary with cumulative SO_2 emission and control. Power stations are ordered by decreasing SO_2 emission. Costs generally increase with cumulative capacity because power stations decrease in size the more plants that are added, reducing economies of scale; and because the capacity factors and emissions of the stations generally decrease so the capital costs of ECT are distributed over less emission reduction.

Table 8 lists the 100 largest sulphur emitting power stations. Note that data reconciliation difficulties cause problems with individual station results: for example for Teruel, Megalopolis and Provence in this Table.

5.4. Nitrogen oxides: EU27

Figure 8 shows NOx emission abatement and costs for power stations, ordered by decreasing NOx emission. For the same reasons as for SO_2, the trend towards higher removal costs (Euro/tonne) is clearly seen as cumulative capacity (GW_e) increases.

Table 9 lists the largest 100 emitters of NOx.

Figure 5. EU27 plant: cumulative emissions.

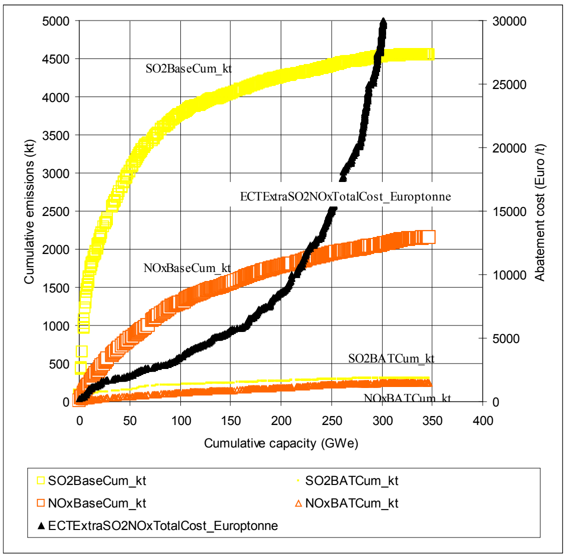


Figure 6. EU27: emissions and additional electricity costs.

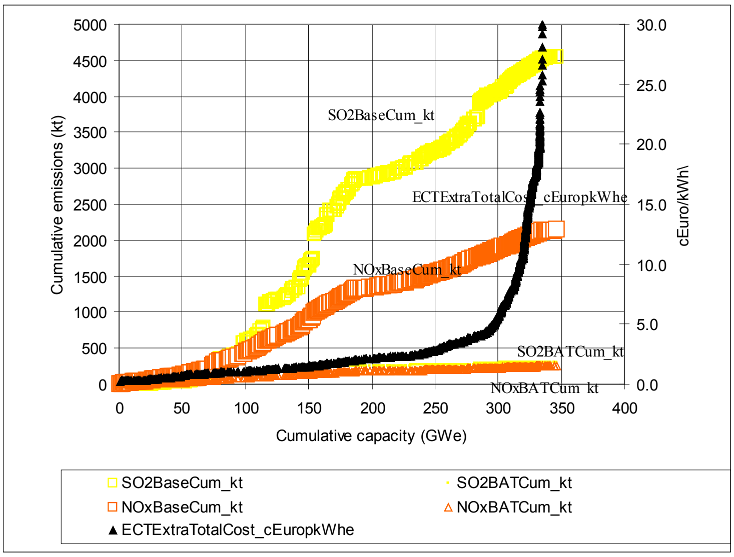


Figure 7. EU27: SO_2 control costs.

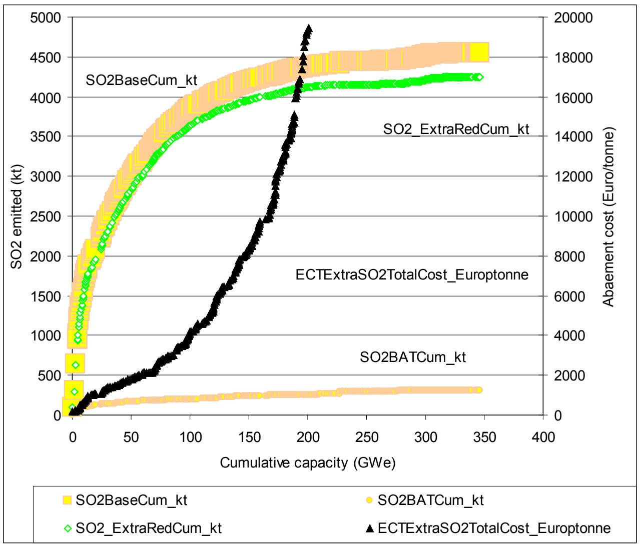


Figure 8. EU27: NOx emission and control costs.

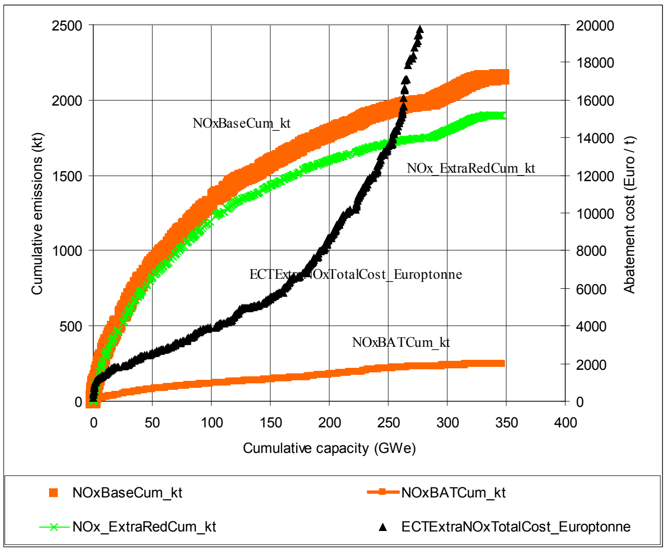


Table 8. EU27: largest sulphur dioxide emitters.

	Cou	Plant	MWe	Fuel	Ash rem.	ECT	Rem.	Base kt	Red.	Emit post BAT kt	Euro/t
1	BGR	Maritsa II	1450	Coal	30%	FGD	40%	332	59%	8	169
2	ESP	Puentes	1400	Coal	30%		30%	312	69%	6	229
3	GRC	Megalopolis A	1400	Coal	30%	FGD	52%	209	46%	6	167
4	ESP	Teruel	1050	Coal	5%	FGD	95%	163	3%	65	289
5	POL	Belchatow	4340	Coal	30%	FGD	72%	140	27%	7	1069
6	BGR	Maritsa I	200	Coal	30%		30%	96	69%	2	163
7	POL	Patnow	1200	Coal	30%		30%	88	69%	2	655
8	GBR	Cottam	2008	Coal	5%		5%	67	93%	1	1432
9	ESP	Meirama	550	Coal	30%		30%	63	69%	1	345
10	ESP	Compostilla	1312	Coal	5%		27%	62	72%	2	1019
11	POL	Kozienice	2600	Coal	5%	FGD	85%	57	13%	7	997
12	PRT	Sines	1256	Coal	5%		5%	57	93%	1	1211
13	ESP	La Robla	620	Coal	5%		5%	57	93%	1	585
14	ROM	Craiova	240	Coal	30%		30%	56	69%	1	283
15	ROM	Turceni	2310	Coal	30%		30%	52	69%	1	1393
16	POL	Rybnik	1720	Coal	5%	Inj	48%	48	50%	2	1315
17	EST	Eesti	1610	Oilshale	10%		10%	47	88%	1	1423
18	BGR	Bobovdol	630	Coal	30%		30%	47	69%	1	530
19	ROM	Drobeta	200	Coal	30%		30%	45	69%	1	340
20	HUN	Oroszlnany	235	Coal	5%		5%	45	93%	1	389
21	GBR	Eggborough	2065	Coal	5%		5%	44	93%	1	2135
22	SVK	Novaky	645	Coal	30%	FGD	30%	42	69%	1	495
23	GBR	Ferrybridge	1470	Coal	5%		5%	41	93%	1	1809
24	GBR	Longannet	2400	Coal	5%		5%	41	93%	1	2814
25	GBR	Kingsnorth	1455	Coal	5%		5%	37	93%	1	1935
26	BGR	Varna	1260	Coal	5%		5%	37	93%	1	1444
27	GRC	Amyntaio	600	Coal	30%		30%	36	69%	1	723
28	GBR	West Burton	2000	Coal	5%	FGD	90%	36	8%	7	1677
29	GRC	Megalopolis B	0	X				34			
30	GBR	Aberthaw	1425	Coal	5%		5%	34	93%	1	1877
31	POL	Turow	1270	Coal	30%	Inj	58%	33	41%	1	2109
32	GBR	Rugeley	1000	Coal	5%		5%	32	93%	1	1604
33	SVN	Trbovlje	125	Coal	20%		20%	31	78%	1	373
34	*GBR*	*Lynemouth*	*390*	*Coal*	*5%*		*5%*	*30*	93%	1	830
35	GBR	Fiddlers Ferry	1926	Coal	5%		5%	30	93%	1	2948
36	POL	Jaworzno	1565	Coal	5%	FGD	5%	28	93%	1	2120
37	IRL	Moneypoint	915	Coal	5%		5%	27	93%	1	1686
38	GBR	Didcot	2000	Coal	5%		5%	27	93%	1	3000
39	GBR	Drax	3960	Coal	5%	FGD	90%	27	8%	5	4560
40	ESP	Almeria	1100	Coal	5%	FGD	94%	26	4%	8	1038
41	ESP	Velilla	0	X				25			
42	POL	Kosciuszko	1800	Coal	5%	FGD	90%	24	8%	5	1800
43	ESP	Abono	903	Coal	5%		5%	24	93%	0	1921
44	GBR	Ironbridge	1000	Coal	5%		5%	22	93%	0	2145
45	BGR	Maritsa III	840	Coal	30%	FGD	93%	22	6%	4	1038
46	POL	Ostroleka	676	Coal	5%		5%	22	93%	0	1247
47	*ESP*	*Guardo*	*498*	*Coal*	*5%*		*5%*	*22*	93%	0	1089
48	GBR	Cockenzie	1200	Coal	5%		5%	21	93%	0	2477
49	POL	Konin	220	Coal	30%	FGD	76%	21	23%	1	1128
50	DEU	Jänschwalde	3000	Coal	30%	FGD	96%	20	2%	8	6463

Table 8 (continued). EU27: largest sulphur dioxide emitters.

	Cou	Plant	MWe	Fuel	Ash. rem	ECT	Rem.	Base kt	Red.	Emit post BAT kt	Euro/t
51	CYP	Dhekelia	360	Oil			0%	20	98%	0	747
52	ROM	Govora	100	Coal	30%		30%	20	69%	0	576
53	GRC	Lavrio	720	Gas			0%	20	0%	20	
54	ESP	Narcea	569	Coal	5%		5%	19	93%	0	1670
55	PRT	Pego	628	Coal	5%		5%	19	93%	0	1580
56	POL	Skawina	580	Coal	5%	FGD	13%	19	85%	0	1511
57	ROM	Brasov	100	Coal	30%		30%	19	69%	0	620
58	ESP	Anllares	350	Coal	5%		5%	19	93%	0	1167
59	ESP	Soto De Ribera	672	Coal	5%		5%	18	93%	0	1855
60	BGR	Republica I	130	Coal	5%		5%	18	93%	0	737
61	ROM	Giurgiu	150	Coal	30%		30%	18	69%	0	632
62	HUN	Matra	812	Coal	30%	FGD	80%	18	18%	1	1500
63	POL	Siekierki	622	Coal	5%	FGD	66%	17	32%	1	829
64	GRC	Aliveri	300	Coal	20%		20%	17	78%	0	835
65	GBR	Ratcliffe	2000	Coal	5%	FGD	90%	16	8%	3	3245
66	HUN	Banhida	100	Coal	5%		5%	16	93%	0	774
67	POL	Lagisza	840	Coal	5%	FGD	90%	16	8%	3	1450
68	ROM	Suceava	100	Coal	30%		30%	16	69%	0	611
69	ESP	Los Barrios	550	Coal	5%		5%	16	93%	0	1719
70	ROM	Paroseni	300	Coal	5%		5%	16	93%	0	973
71	ESP	Lada	505	Coal	5%		5%	16	93%	0	1583
72	GBR	Kilroot	390	Coal	5%		5%	15	93%	0	1625
73	GRC	Linoperamata	0	X				15			
74	ESP	Alcudia	510	Coal	5%	FGD	62%	14	36%	1	1008
75	ITA	Porto Tolle	2640	Oil			0%	14	98%	0	6837
76	BGR	Svishtov	120	Coal	5%		5%	14	93%	0	918
77	*ITA*	*Sicilia*	*1388*	*Oil*			*0%*	*14*	98%	0	3503
78	GBR	Tilbury	700	Coal	5%		5%	14	93%	0	2789
79	GRC	Ptolemais	620	Coal	30%		30%	14	69%	0	2138
80	DEU	Lippendorf	2110	Coal	30%	FGD	87%	14	12%	2	2035
81	FRA	Emile Huchet	1164	Coal	5%	FBC	5%	14	93%	0	3438
82	ESP	Cercs	175	Coal	5%		5%	14	93%	0	1004
83	CZE	Prunerov	1490	Coal	30%	FGD	93%	13	6%	3	2692
84	POL	Adamow	600	Coal	30%		30%	13	69%	0	2078
85	FRA	Blenod/ P. Mousson	1000	Coal	5%		5%	13	93%	0	3461
86	ITA	Fusina	976	Coal	5%	FGD	61%	13	37%	1	2655
87	ROM	Iasi	100	Coal	30%		30%	12	69%	0	901
88	POL	Krakow	1380	Coal	5%		5%	12	93%	0	4666
89	GRC	Kardia	1200	Coal	30%		30%	12	69%	0	4290
90	ITA	San Filippo	1280	Oil			0%	12	98%	0	4217
91	DEU	Frimmersdorf	2400	Coal	30%	FGD	89%	12	9%	2	7911
92	ITA	Genova	295	Coal	5%		5%	12	93%	0	1771
93	HUN	Pecs	190	Coal	5%		5%	12	93%	0	1343
94	ITA	Brindisi Sud	2640	Coal	5%	FGD	90%	11	8%	2	4924
95	BEL	Ruien	255	Coal	5%		5%	11	93%	0	1830
96	FRA	Provence	14	Oil			0%	11	98%	0	246
97	FRA	Le Havre	1415	Coal	5%	FGD	39%	11	59%	0	4187
98	DEU	Boxberg	4668	Coal	30%	FGD	77%	11	21%	1	9846
99	MLT	Marsa	152	Oil			0%	11	98%	0	1178
100	CZE	Tusimice	1130	Coal	30%	FGD	93%	10	6%	2	2145

Table 9. EU27: largest nitrogen oxide emitters.

	Cou	Plant	MWe	Fuel	Base kt	ECT	Rem.	BAT Red kt	Emit post BAT kt	Euro/t
1	GBR	Drax	3960	Coal	58	Boi	50%	51	7	1838
2	POL	Belchatow	4340	Coal	40			38	2	3918
3	BGR	Maritsa II	1450	Coal	39			37	2	1247
4	ESP	Compostilla	1312	Coal	35			33	2	1391
5	ESP	Teruel	1050	Coal	31			30	2	1252
6	GBR	Aberthaw	1425	Coal	24			23	1	1791
7	PRT	Sines	1256	Coal	23	Boi	42%	21	2	1643
8	GBR	Ratcliffe	2000	Coal	23	Boi	50%	20	3	2170
9	GBR	West Burton	2000	Coal	23	Boi	42%	20	2	2464
10	BGR	Maritsa III	840	Coal	23			21	1	1247
11	ESP	La Robla	620	Coal	23			21	1	1007
12	GBR	Cottam	2008	Coal	22	Boi	50%	19	3	2227
13	GRC	Dimitrios	1570	Coal	22	Boi	50%	19	3	1801
14	ESP	Velilla	0	X	21					
15	GBR	Kingsnorth	1455	Coal	20	Bo i	42%	18	2	1878
16	IRL	Moneypoint	915	Coal	20	Boi	50%	18	2	1175
17	GRC	Kardia	1200	Coal	20			19	1	2040
18	GBR	Ferrybridge	1470	Coal	20	Boi	50%	17	2	1912
19	ROM	Turceni	2310	Coal	20			19	1	3193
20	GBR	Longannet	2400	Coal	19	Boi	50%	17	2	2930
21	ESP	Puentes	1400	Coal	19			18	1	2873
22	POL	Kozienice	2600	Coal	19			18	1	4169
23	GBR	Eggborough	2065	Coal	19	Boi	50%	17	2	2421
24	POL	Rybnik	1720	Coal	19	Boi	42%	17	2	2427
25	ESP	Abono	903	Coal	17	Boi	50%	15	2	1346
26	DEU	Jänschwalde	3000	Coal	17	Boi	42%	16	2	5159
27	DEU	Marl	484	Coal	16	SCR	80%	11	5	525
28	ESP	Anllares	350	Coal	16			15	1	887
29	CZE	Prunerov	1490	Coal	16			15	1	3070
30	CZE	Pocerady	1000	Coal	16			15	1	2172
31	ESP	Almeria	1100	Coal	15	Boi	50%	13	2	1562
32	BGR	Varna	1260	Coal	15			14	1	2482
33	GBR	Didcot	2000	Coal	15	Boi	50%	13	2	2583
34	DEU	Frimmersdorf	2400	Coal	15		50%	14	1	6780
35	DEU	Eschweiler	0	X	14					
36	POL	Turow	1270	Coal	14			13	1	4258
37	GBR	Tilbury	700	Coal	14			13	1	1907
38	GBR	Fiddlers Ferry	1926	Coal	14	Boi	42%	12	1	3369
39	BGR	Bobovdol	630	Coal	13			13	1	1513
40	DEU	Neurath	2100	Coal	13	Boi	30%	12	1	3827
41	ESP	Narcea	569	Coal	12			11	1	1741
42	GBR	Cockenzie	1200	Coal	12			11	1	2992
43	POL	Opole Works	1492	Coal	12	Boi	42%	11	1	2677
44	*ESP*	*Guardo*	*498*	*Coal*	*12*			11	1	1345
45	POL	Kosciuszko	1800	Coal	11	Boi	42%	10	1	3888
46	ESP	Soto De Ribera	672	Coal	11			11	1	2024
47	FRA	Le Havre	1415	Coal	11			10	1	3795
48	POL	Patnow	1200	Coal	11			10	1	4324
49	ESP	Meirama	550	Coal	11			10	1	1667
50	ROM	Craiova	240	Coal	11			10	1	1053

Table 9 (continued). EU27: largest nitrogen oxide emitters.

	Cou	Plant	MWe	Fuel	Base kt	ECT	Rem.	BAT Red kt	Emit post BAT kt	Euro/t
51	PRT	Pego	628	Coal	10		50%	10	1	1940
52	ITA	Brindisi Sud	2640	Coal	10	Boi/SCR	88%	4	6	7589
53	BGR	Maritsa I	200	Coal	10			9	1	1103
54	POL	Jaworzno	1565	Coal	10	Boi	50%	9	1	2744
55	DEU	Boxberg	4668	Coal	10	Boi	50%	9	1	10197
56	FRA	Vazzio	160	Oil	10			9	1	689
57	DEU	Gelsenk./ Schloven	1344	Coal	10	Boi/SCR	90%	4	6	11148
58	GBR	Rugeley	1000	Coal	10	Boi	50%	9	1	2717
59	*GBR*	*Lynemouth*	*390*	*Coal*	*9*	*Boi*	*50%*	8	1	1434
60	CZE	Tusimice	1130	Coal	9			8	1	3825
61	SVN	Sostanj	745	Coal	9			8	1	2602
62	FRA	Jarry Nord	0	X	9					
63	ROM	Drobeta	200	Coal	9			8	1	1253
64	POL	Laziska	1155	Coal	9	Boi	40%	8	1	3638
65	ESP	Los Barrios	550	Coal	8	Boi	42%	8	1	1762
66	EST	Eesti	1610	Oilshale	8			8	1	5759
67	ESP	Alcudia	510	Coal	8	Boi	42%	8	1	1403
68	FRA	Bellefontaine	0	X	8					
69	BEL	Ruien	255	Coal	8	Boi	42%	7	1	1342
70	POL	Dolna Odra	1600	Coal	8	Boi	42%	7	1	4896
71	GRC	Rhodes	234	Oil	8			7	1	724
72	GBR	Ironbridge	1000	Coal	8	Boi	50%	7	1	3093
73	GRC	Ptolemais	620	Coal	8			7	0	3107
74	FRA	Provence	14	Oil	8			7	1	371
75	GRC	Amyntaio	600	Coal	8			7	0	2733
76	PRT	Vitoria	115	Oil	7			7	1	1009
77	ESP	Lada	505	Coal	7			7	0	2254
78	FRA	Cordemais	1745	Coal	7			7	0	6809
79	GRC	Chanion	0	X	7					
80	*ITA*	*Sicilia*	*1388*	*Oil*	*7*			7	1	2663
81	GBR	Kilroot	390	Coal	7	Boi	50%	6	1	1807
82	GRC	Linoperamata	0	X	7					
83	FRA	Port	87	Oil	7			6	1	1111
84	FRA	Blenod/ P. Mousson	1000	Coal	7	Boi	50%	6	1	3178
85	POL	Ostroleka	676	Coal	7	Boi	50%	6	1	1848
86	ITA	Fusina	976	Coal	7	Boi/SCR	88%	3	4	5596
87	FRA	Emile Huchet	1164	Coal	7		60%	6	0	5025
88	DEU	Lippendorf	2110	Coal	7	Boi	30%	6	1	6575
89	ESP	Cordoba / P. Nuevo	313	Coal	6			6	0	1803
90	CZE	Melnik	1270	Coal	6			6	0	5680
91	DNK	Studstrup	760	Coal	6	Boi	50%	6	1	2847
92	DEU	Schwarze Pumpe	1600	Coal	6	Boi	50%	5	1	5038
93	POL	Lagisza	840	Coal	6	Boi	50%	5	1	3690
94	HUN	Matra	812	Coal	6			5	0	5365
95	POL	Siekierki	622	Coal	6	Boi	42%	5	1	2401
96	POL	Adamow	600	Coal	5			5	0	4001
97	POL	Skawina	580	Coal	5			5	0	3748
98	DNK	Odense/ Fyns	443	Coal	5	Boi	50%	5	1	1621
99	SVK	Novaky	645	Coal	5		60%	5	0	3393
100	ESP	Pasajes	214	Coal	5			5	0	1754

5.5. Summary: EU27

Table 10 summarises the emissions, reductions and costs of abatement for the EU27 for the largest SO_2 and NOx emitting power stations. The power stations are ordered by the decreasing sum of baseline SO_2 and NOx emissions – i.e. prior to the application BATECT. The Table shows the result for the first 50, 100 and 200 power stations.

This describes the content of Table 10:

- Per cent of total emissions is the fraction, before and after the application of BATECT, of total anthropogenic land-based emissions for the EU27.
- Per cent of all power station emissions is the fraction of total power station emissions for the EU27.
- Emission shows the emissions in kilotonnes (kt); baseline, after the application of BATECT, and the reduction due to BATECT.
- Cost shows the total expenditure on BATECT (MEuro/a) and the average abatement cost (Euro/t).

Table 10. EU27 power stations: summary of emissions and costs.

First 50 power stations			SO_2	NOx	SO_2+NOx	CO_2 (Mt)
% of total emissions		Base	36%	8%	19%	9%
		Reduction	33%	7%	18%	-0.2%
% of all power station emissions			61%	37%	53%	25%
Emission	Baseline	kt	2901	858	3759	342
	BATECT	kt	173	73	245	336
	Reduction	kt	2729	785	3514	-6
	Reduction	%	94%	92%	93%	-1.7%
Cost	Total	MEuro/a	2530	1809	4339	
	Total	Euro/t	927	2303	1235	

First 100 power stations			SO_2	NOx	SO_2+NOx	CO_2 (Mt)
% of total emissions		Base	44%	11%	25%	16%
		Reduction	41%	10%	23%	-0.2%
% of all power station emissions			76%	53%	68%	44%
Emission	Base	kt	3597	1240	4837	602
	BATECT	kt	227	121	347	593
	Reduction	kt	3370	1119	4489	-9
	Reduction	%	94%	90%	93%	-1.5%
Cost	Total	MEuro/a	3988	2902	6890	
	Total	Euro/t	1184	2592	1535	

First 200 power stations			SO_2	NOx	SO_2+NOx	CO_2 (Mt)
% of total emissions		Base	50%	14%	29%	21%
		Reduction	47%	12%	27%	-0.3%
% of all power station emissions			86%	67%	80%	58%
Emission	Base	kt	4098	1567	5664	787
	BATECT	kt	275	166	441	776
	Reduction	kt	3822	1401	5223	-11
	Reduction	%	93%	89%	92%	-1.4%
Cost	Total	MEuro/a	5899	4139	10038	
	Total	Euro/t	1543	2955	1922	

From the Table it can be seen that the 100 most polluting plants in the EU are responsible for 44 per cent of the total EU land-based SO_2 emissions, and 76 per cent of the EU power plant SO_2 emissions. As regards NOx, the same 100 plants make up 11 per cent of the total land-based emissions, and 53 per cent of those from power plants.

The analysis of emission abatement and associated costs indicate that application of advanced emission control technologies to the 100 most polluting plants in the EU could reduce annual emissions of SO_2 and NOx by approximately 3,400 and 1,100 kilotonnes respectively, at a total cost of about 6.9 billion Euro, equalling an average cost of 1,500 Euro per tonne pollutant reduced.

5.6. All power stations

This section presents results for all power stations in the database, covering the EU27 and countries peripheral to the EU27 – the most important being western Russia, Ukraine and Turkey. It is to be noted that emissions are calculated for power stations in these countries and no independent emissions data such as in EPER have been utilised.

The pattern of results is essentially the same as for the EU27, see Figures 9, 10 and 11.

Table 11 and 12 in Annex 2 list the largest SO_2 and NOx emitting power stations. It may be seen that non-EU power stations are heavily represented. This is because the general levels of emission control are lower and there are many large coal plant in non-EU countries.

Figure 9. All plant: cumulative emissions SO_2 + NOx.

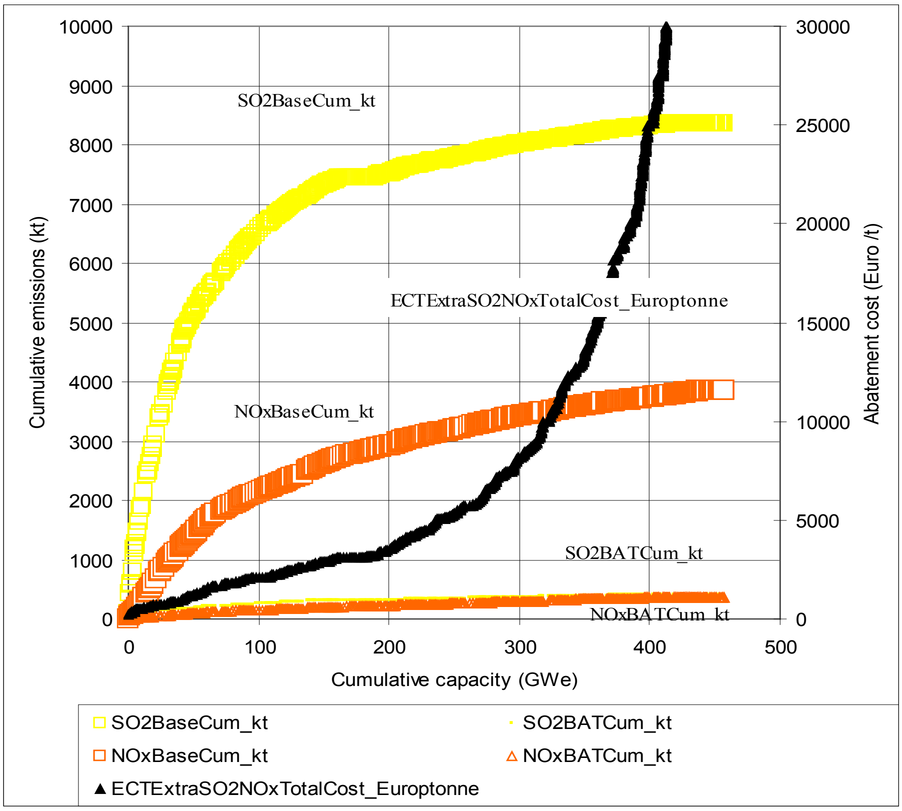


Figure 10. All plant: SO_2 control costs.

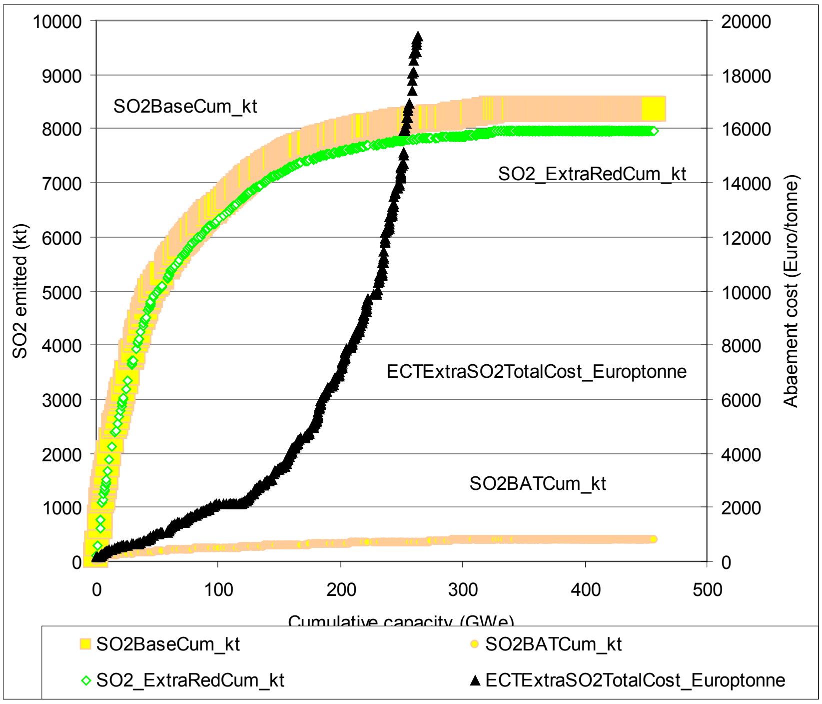
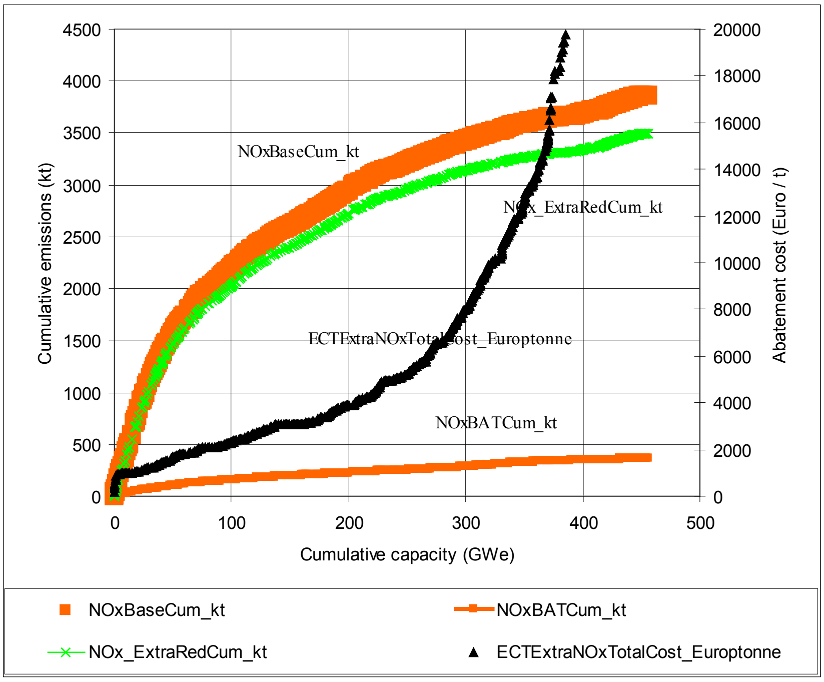


Figure 11. All plant: NOx control costs.



6. Health impacts and costs

6.1. Effects considered and excluded from the analysis

Table 13 identifies the impacts of SO_2 and NOx that are and are not quantified in this report. Although the analysis includes assessment of impacts to both health and crops, it is the health benefits that dominate the analysis.

As noted above, the abatement of SO_2 and NOx has implications for emissions of other pollutants also. Of these, only the change in emissions of CO_2 (which increases) is accounted for specifically. The change in impact resulting from a change in emissions of other pollutants such as mercury and fine particles is not described because of a lack of data.

Table 13. Mapping primary (emitted) pollutants to impacts.

	NOx	SO_2
Particles: human health	✓	✓
Ozone: human health	✓	
Primary pollutants: human health	×	×
Ecosystems: acidification	×	×
Ecosystems: eutrophication	×	
Ecosystems: ozone effects	×	
Crops: ozone effects	✓	
Materials: material degradation	×	×
Materials: soiling		

Key: × identifies impacts unquantified in this report; ✓ identifies quantified impacts; blank cells indicate no link between pollutant and impact.

The health impacts that have been quantified for this report are listed in detail in Table 14. More information on the impacts omitted from the analysis is given in Table 15. Note that the term 'chronic effects' relates to impacts arising from long-term exposures (for months or years), whilst 'acute ef-

Table 14. Health impacts quantified in the analysis undertaken for this report.

Human exposure to $PM_{2.5}$	
Chronic effects on:	
Mortality	Adults over 30 years
	Infants
Morbidity	Bronchitis
Acute effects on:	
Morbidity	Respiratory hospital admissions
	Cardiac hospital admissions
	Consultations with primary care physicians
	Restricted activity days
	Use of respiratory medication
	Symptom days
Human exposure to ozone	
Acute effects on:	
Mortality	
Morbidity	Respiratory hospital admissions
	Minor restricted activity days
	Use of respiratory medication
	Symptom days

Table 15. Effects omitted from the analysis.

Effect	Comments
Health	
Ozone chronic – mortality Ozone chronic – morbidity	No information on possible chronic effects, suspected but not proven
Direct effects of SO_2 , NOx	
Agricultural production	
Direct effects of SO_2 and NOx	Negligible according to past work
N deposition as crop fertiliser	Negligible according to past work
Visible damage to marketed produce	Locally important for some crops, but insignificant at the European scale
Interactions between pollutants, with pests and pathogens, climate…	Exposure-response data unavailable
Acidification/liming	Negligible according to past work
Materials	
SO_2/acid effects on utilitarian buildings	CAFE analysis found that these impacts are only a few percent of health damages
Effects on cultural assets, steel in re-inforced concrete	Lack of stock at risk inventory and valuation data
PM and building soiling	
Effects of ozone on paint, rubber	
Ecosystems	
Effects on biodiversity, forest production, etc. from excess ozone exposure, acidification and nitrogen deposition	Valuation of ecological impacts is currently too uncertain
Visibility	
Change in visual range	Impact of little concern in Europe
Drinking water	
Supply and quality	Limited data availability

fects' are those caused by exposure to elevated pollution levels over a shorter period, typically one or more days.

6.2. Quantification of impacts and economic damage related to emissions of NOx and SO_2

6.2.1. Overview of methods for quantification of NOx and SO_2 damages

Analysis contained in this report follows the impact pathway methodology developed in the ExternE Project funded by EC DG Research. Methods for estimating the impacts and economic damage associated with emissions from the EU25 are described by AEA Technology and others (2005) for development of the updated BeTa (Benefits Table) database. For each country in the EU (excluding Bulgaria, Cyprus and Romania), BeTa provides average damage estimates in terms of Euro/tonne emission of ammonia, NOx, $PM_{2.5}$, SO_2 and VOC. BeTa has already been used to support the development of the IPPC (Integrated Pollution Prevention and Control) Bureau's position on 'Economics and Cross Media Effects' (EIPPC Bureau, 2005), and in an earlier quantification of the health impacts of emissions from large point sources (Holland, 2006).

The impact pathway described by the analysis is as follows:

Emission of pollutants

⇨Dispersion and physical/chemical transformation of pollutants

⇨ Exposure of people

⇨ Quantification of impacts

⇨ Valuation of impacts

The method gives two sets of useful data to add to the emission estimates contained in the SENCO database:

1. Information on the number of cases of ill health and loss of life expectancy linked to exposure to secondary PM from emissions of SO_2 and NOx from large point sources in Europe.

2. Information on the total value attached to these occurrences of ill health, according to surveys performed using economic techniques to assess the 'willingness to pay' (WTP) of members of the public to a change in the risk of being ill or dying early. Some argue that it is unethical to value health in this manner. However, this argument ignores the fact that health is routinely valued by policy makers through the allocation of funds to medical services, foreign aid and so on, though this is rarely done in a way that transparently identifies or reflects underlying values. The methods used here have a distinct advantage in defining a consistent and transparent weighting scheme. Stakeholders who do not accept the values adopted here are of course free to substitute their own.

6.2.2. Input data for the BeTa database

The dispersion modelling used in BeTa takes outputs from the EMEP model (Simpson and Wind, 2005). The EMEP model was run many times to quantify the change in pollution climate across the EU25 arising from a 15 per cent change in emission of pollutants including NOx and SO_2 from each country in the year 2010. These impacts were then scaled back to estimate the change in concentration across Europe arising from emission of 1 tonne of pollutant. The modelling includes assessment of the formation of secondary pollutants such as ozone (from NOx and VOC emissions) and nitrate and sulphate particulates (from NOx and SO_2 emissions respectively).

These changes in pollution concentrations were then combined with population (based on UN data sources) on a 50 x 50 km grid. The "population weighted pollutant concentrations" so derived for each grid cell were then summed and combined with the exposure-response functions adopted under the CAFE programme to quantify the average number of cases or events of death and ill health (following the list above) associated with the release of 1 tonne of each pollutant in each country. Results were then multiplied by valuation factors to show the economic value of each impact, and summed to give a total damage per unit pollution emission, expressed in Euro/tonne.

The key parameters of incidence rate (specific to the population age groups of each function), response functions and valuation data are shown here in Table 16. In CAFE the valuation of mortality was performed using four figures – a lower and higher estimate of the value of a life year (VOLY) and a lower and higher estimate for the value of statistical life (VSL). There is roughly a factor four difference between the extremes of the range.

For this report the most conservative of these figures, the lower estimate of €52,000/VOLY, has been adopted in line with recommendations made under the ExternE

Project. ExternE also recommends that it is most meaningful to report mortality in terms of life years lost (LYL). Although estimates of the number of deaths linked to operation of each plant are also provided, these figures should be regarded as less robust, perhaps very significantly so, than the reduction in longevity expressed as LYL. There is also a question of the roles of other factors in 'death' that are unaccounted for by pollution. This complication should be avoided when using the LYL concept.

More recent work (Desaigues et al, 2007) has been done to quantify the VOLY. However, the figures cited in that work are being further revised and it is yet to be peer reviewed. It seems likely that the final recommendation from NEEDS for a VOLY applicable to the EU27 will be around 40,000 Euro. Applying this figure would generate damages about 15 per cent lower than those quantified here.

6.2.3. Quantification of impacts outside the EU25

The version of BeTa used here lacks quantification for Bulgaria, Cyprus and Romania. For Cyprus results did not compare well with other countries and it was considered likely that significant errors were present, linked to the position of Cyprus within the dispersion modeling domain. At the time that the BeTa analysis was performed specific modelling of emissions from non-EU countries (including Bulgaria and Romania as they had not then joined the EU) was unavailable. Analysis undertaken for the EC DG Research Methodex Project (Holland, 2006), however, has shown that for the EU

Table 16. Response functions and valuation data for quantification of health damages linked to PM and ozone exposure (based on Hurley et al, 2005).

Effect	Response functions[1]	Valuation *€/case or event*
Effects of $PM_{2.5}$		
Change in rate for chronic mortality (life years lost, people aged >30) [2]	6%	52,000
Change in rate for chronic mortality (deaths, people aged >30) [2]	6%	980,000
Change in rate for infant mortality (ages 1–12 months)	4%	1,500,000
New incidence of chronic bronchitis, population aged >27 (cases)	26.5	190,000
Respiratory hospital admissions, all ages	7.03	2,000
Cardiac hospital admissions, all ages	4.34	2,000
Restricted activity days (RADs) working age population	90,200	82
Respiratory medication use by adults (days)	91	1
Respiratory medication use by children (days)	18	1
Days with lower respiratory symptoms (LRS), including cough, among adults with chronic symptoms	130,000	38
Days with LRS (including cough) among children	186,000	38
Effects of ozone		
Acute mortality (life years lost, VOLY median valuation)	0.30%	52,000
Respiratory hospital admissions, ages over 65	12.5	2,000
Minor restricted activity days, ages 18-64	11,500	38
Respiratory medication use by adults with persistent asthma (days)	73,000	1

[1] Response functions are expressed as % change for death rates and absolute change per 100,000 relevant population group for morbidity, both per 10 µg/m³ pollutant.

[2] Life years lost and the number of deaths are different ways of expressing the same impact and their results are therefore not additive.

countries a good relationship exists between damage and population density within each country for effects of primary particles, SO_2 via sulphate aerosol and NOx via nitrate aerosol but not ozone. These relationships are as follows:

NOx damage (€/t) = 40.6 x national population density

SO_2 damage (€/t) = 39.3 x national population density

In both cases lines were fitted with the intercept equal to zero (on the grounds that health damage would be zero if there were no people present). These relationships have therefore been applied for Bulgaria and Romania. The fact that these functions consider only national population density should not be assumed to imply that the quantification of effects of emissions from any country is limited to that country's borders, or that effects of emissions from that country on its neighbours are unimportant. The analysis of each country's emissions extends across the full EU domain.

6.2.4. Data quality

Whilst the EMEP model is widely respected in Europe, there are some caveats relating to its use in this work. Firstly, the results used represent an average for each country, factoring out the specificity of damage relative to the height of emission and the precise location of each plant. To some extent this problem is limited in this analysis because it focuses on impacts of secondary pollutants (sulphate and nitrate aerosols) arising following the release of SO_2 and NOx. These secondary pollutants take some time to form in the atmosphere, making the specificity of site less important. Even so, variability of the order of a factor of around 2 about best estimates may be expected within a large country. For primary particles, however, a higher degree of variability would be found.

Turning to the response functions used, in common with other studies in this field, and the advice of WHO given in answers to questions raised by the CAFE stakeholders, the following positions have been adopted:

1. That there is no threshold for the effects of fine particles on health, with the response function being linear down to a concentration of zero. Given a lack of evidence for a threshold, this seems unlikely to introduce a bias to the analysis.

2. That ozone effects are quantified only above a concentration of 35 ppb (parts per billion). This may bias results to underestimation of damage.

3. That all types of particle are equally damaging per unit mass. It is possible that this biases results to overestimation of damage in this study.

4. That there are no separate effects arising from exposure to SO_2 and NO_2, beyond those that might be implicitly accounted for in the quantification of damages from secondary particles. If incorrect, this would bias results to underestimation of damage.

WHO also recommended that impacts of chronic mortality be quantified using a risk rate of 6% per 10 $\mu g/m^3$ for the main analysis, and a lower rate of 4% for sensitivity analysis. Here, only the 6% rate has been used. Impacts based on this lower rate can be obtained simply by reducing the results for the number of LYL or deaths by one third.

A formal validation of the health impact assessment, with attribution of specific cases of ill health or death to the operation of a large point source is not possible in any but the most extreme cases. However, direct evidence that reducing pollutant emissions reduces the incidence of ill-health is available through 'intervention studies' that typically examine death rates or hospital admissions in restricted areas where some specific action has been taken to suddenly reduce pollutant emissions. A famous example concerns the banning of coal burning in Dublin. Unfortunately, these studies are useful for validation of the impact of primary pollutants only.

6.3. Valuation of increased emissions of CO_2

Control of SO_2 and NOx requires energy input which inevitably leads to higher emissions of CO_2 which need to be offset against the benefits of pollution controls.

Estimates of the cost per tonne of CO_2 released are extremely variable, being dependent on numerous assumptions such as the rate of warming and future economic growth. The approach used here is not to use such estimates to value the increase in emissions of CO_2 that is associated with additional abatement of NOx and SO_2, but to value CO_2 in terms of the marginal cost of abatement estimated for the EU in relation to its obligations under the Kyoto Protocol (19 Euro/tonne). This was the approach proposed for the European Commission's CAFE (Clean Air For Europe) Programme, though it was not eventually needed in that analysis. The logic of using an abatement cost is that international obligations require countries to control to a specific level. Once that level has been reached it is presumed that a country will not go any further with its abatement. If a driver such as NOx and SO_2 control causes emissions of CO_2 rise for any reason further abatement will be needed to bring national emissions back to the required level. Thus there would not be a change in climate change related damages, but there would be a change in the overall cost of controlling greenhouse gases.

6.4. Results

Power stations across the EU26 (Cyprus excluded from the EU27) have been ranked in terms of baseline (pre-BATECT) emission of SO_2 and NOx combined, and then benefits quantified against achievement of BATECT in line with the methods described above. Results for the top 100 power stations from this list are shown in Table 17. One plant in Cyprus has been excluded because of methodological problems in quantifying benefits for the country, outlined above.

The same caveats already given for the cost-effectiveness assessment concerning results for individual plant apply to the benefits analysis also, with the added uncertainties of the benefits assessment, for example that this part of the analysis does not account for variation in damage according to the location of plant within a country. General conclusions are therefore to be considered more reliable than the results for individual power stations.

The average benefit:cost ratio for the 100 plant listed is 3.4[1], indicating that there is a good basis for moving to BATECT as defined here. For eight plant, however, the ratio is <1 (i.e. costs exceed benefits). Five of these plant are in Greece, and one in each of Estonia, Italy and Poland. There is also one plant (Provence, in France) for which, in comparison to others, the ratio of benefits to costs seems very large. There are various factors that may explain these apparent anomalies:

- Uncertainties in the LCP database. The benefits analysis has, however, been restricted to the most polluting plant on the grounds that these tend to be the plant for which emissions data are likely to be most reliable.

[1] Note that this falls to 2.8 when the ratio is calculated as total benefit/total cost for the top 100 plant, rather than by averaging ratios for individual plant.

- Systematic variation in damage between plant in different countries in Europe. Damage per tonne estimates for countries at the edge of the continent are lower than those towards the centre. This largely explains why plant in Estonia and Greece have low benefit:cost ratios. Accepting the methods for health damage quantification, damage estimates for these countries may be artificially low for two reasons:

  - Exclusion of effects on people outside of the EU27.

  - Exclusion of damage to some receptors, such as ecosystems.

Figure 12 shows that a small number of plant account most of the benefits of abating NOx and SO_2. Indeed, only 331 plant account for 90 per cent of all benefits. A separate sensitivity analysis adopting the lower value of a life year that seems likely to be recommended from the NEEDS research project (Desaigues et al, 2007), as discussed above, has not been conducted. The overall benefit:cost ratios are sufficiently in excess of unity that this sensitivity would not lead to dramatically different results.

Figure 12. Cumulative distribution of benefits.

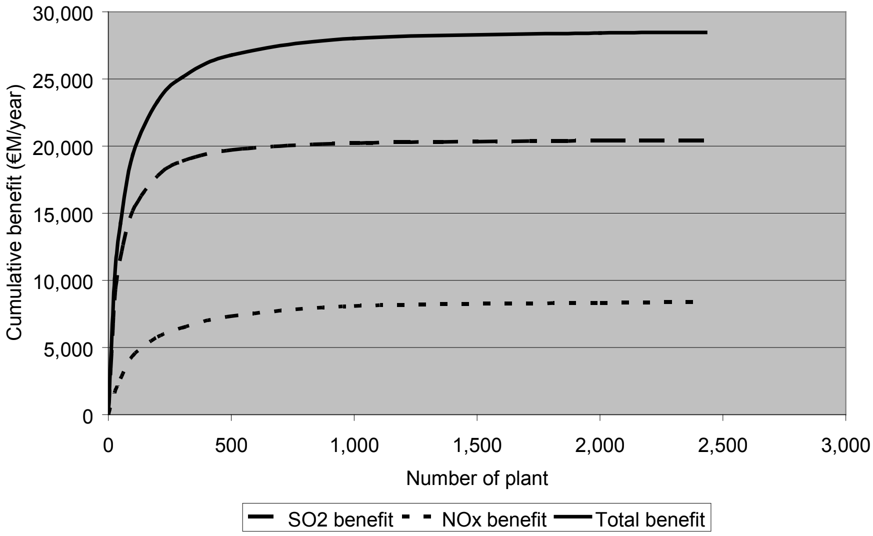


Table 18. Summary results for the 50, 100 and 200 power stations emitting the most NOx+SO_2 combined in the EU27.

	50 highest emitters	100 highest emitters	200 highest emitters
SO_2 abatement benefit (€M)	11,749	15,170	17,779
NOx abatement benefit (€M)	2,660	4,387	5,777
CO_2 penalty (€M)	-110	-171	-215
Total benefit (€M)	14,299	19,387	23,341
Reduced mortality (as life years gained)	160,960	207,823	243,567
Reduced mortality (as avoided premature deaths)	15,082	19,473	22,823
Total cost (€M)	4,339	6,890	10,038
Net benefit (€M)	9,960	12,497	13,303
Benefit:cost ratio	**3.30**	**2.81**	**2.33**

Table 17. Costs and benefits of the 100 plant in the EU26 with the largest combined SO_2 and NOx baseline emission.

Rank	Country	Plant	Electrical capacity, MW	Heat capacity, MW	SO_2 benefit, €M/year	NOx benefit, €M/year	CO_2 disbenefit, €M/year	Total benefit, €M/year	Total cost €M/year	Benefit: cost ratio
1	BGR	Maritsa II	1450	0	885	103	3	985	101	9.79
2	ESP	Puentes	1400	0	1315	47	4	1357	122	11.11
3	GRC	Megalopolis A	1400	0	284	3	1	285	70	4.08
4	ESP	Teruel	1050	0	421	77	1	497	65	7.62
5	POL	Belchatow	4340	376	745	147	7	885	290	3.05
6	BGR	Maritsa I	200	0	256	26	1	282	26	11.03
7	POL	Patnow	1200	0	485	39	3	521	100	5.22
8	ESP	Compostilla	1312	0	258	85	3	340	107	3.19
9	GBR	Cottam	2008	0	435	74	4	505	137	3.69
10	GBR	Drax	3960	0	142	198	2	338	191	1.77
11	PRT	Sines	1256	0	196	27	4	219	102	2.14
12	ESP	La Robla	620	0	241	55	2	294	54	5.43
13	POL	Kozienice	2600	266	280	71	1	349	125	2.78
14	ESP	Meirama	550	0	267	26	2	291	38	7.65
15	ROM	Turceni	2310	0	188	70	2	256	131	1.96
16	ROM	Craiova	240	330	201	37	1	238	26	9.15
17	POL	Rybnik	1720	59	257	65	3	319	101	3.16
18	GBR	Eggborough	2065	0	283	65	4	344	132	2.61
19	GBR	Ferrybridge	1470	0	266	68	4	331	106	3.11
20	GBR	Longannet	2400	0	265	67	4	327	163	2.01
21	BGR	Bobovdol	630	0	125	36	1	159	43	3.67
22	GBR	West Burton	2000	0	188	80	1	267	98	2.72
23	GBR	Aberthaw	1425	0	217	89	3	303	103	2.95
24	GBR	Kingsnorth	1455	0	240	71	4	307	105	2.94
25	EST	Eesti	1610	0	84	6	4	86	112	0.77
26	ROM	Drobeta	200	776	162	30	1	192	25	7.62
27	BGR	Varna	1260	0	98	39	1	136	87	1.57
28	IRL	Moneypoint	915	0	128	68	3	194	66	2.93
29	POL	Turow	1270	132	179	52	3	227	124	1.83
30	SVK	Novaky	645	1491	201	26	0	227	37	6.08
31	HUN	Oroszlnany	235	88	211	10	1	220	27	8.03
32	BGR	Maritsa III	840	0	48	60	0	107	45	2.39
33	GRC	Amyntaio	600	0	49	6	2	53	45	1.19
34	GBR	Fiddlers Ferry	1926	0	191	47	3	235	126	1.86
35	GBR	Rugeley	1000	0	207	33	2	238	74	3.24
36	GBR	Didcot	2000	0	174	51	3	222	113	1.97
37	ESP	Almeria	1100	0	78	35	0	113	40	2.82
38	ESP	Abono	903	0	99	40	4	136	65	2.09
39	GBR	Ratcliffe	2000	0	86	79	1	164	86	1.91
40	GBR	Lynemouth	390	0	192	31	2	221	35	6.23
41	DEU	Jänschwalde	3000	0	133	149	1	281	158	1.77
42	POL	Jaworzno	1565	238	151	34	2	182	81	2.26
43	POL	Kosciuszko	1800	130	109	40	0	148	75	1.99
44	ESP	Anllares	350	0	78	39	1	116	34	3.36
45	ESP	Guardo	498	0	91	29	1	119	38	3.13
46	GBR	Cockenzie	1200	0	136	44	2	179	85	2.10
47	SVN	Trbovlje	125	0	188	13	0	201	19	10.31
48	GRC	Kardia	1200	0	16	16	5	27	87	0.31
49	ESP	Narcea	569	0	79	30	2	107	51	2.11
50	GBR	Ironbridge	1000	0	144	27	1	170	68	2.49

Table 17 (continued). Costs and benefits of the 100 plant in the EU26 with the largest combined SO_2 and NOx baseline emission.

Rank	Country	Plant	Electrical capacity, MW	Heat capacity, MW	SO_2 benefit, €M/year	NOx benefit, €M/year	CO_2 disbenefit, €M/year	Total benefit, €M/year	Total cost €M/year	Benefit: cost ratio
51	ESP	Soto De Ribera	672	0	76	28	2	102	54	1.87
52	PRT	Pego	628	0	64	13	2	75	48	1.56
53	CZE	Prunerov	1490	192	85	108	1	193	74	2.59
54	GRC	Dimitrios	1570	70	10	16	5	21	97	0.21
55	POL	Ostroleka	676	238	119	23	1	140	37	3.76
56	GBR	Tilbury	700	0	91	51	2	139	63	2.20
57	DEU	Frimmersdorf	2400	0	110	133	3	239	173	1.39
58	POL	Konin	220	462	108	17	1	124	38	3.28
59	ESP	Los Barrios	550	0	68	20	2	86	40	2.12
60	POL	Skawina	580	437	102	20	1	121	47	2.58
61	GRC	Lavrio	720	0	0	3	0	3	9	0.34
62	ROM	Govora	100	150	72	13	0	84	20	4.20
63	HUN	Matra	812	28	79	29	1	106	53	2.00
64	ESP	Lada	505	0	66	18	1	83	40	2.07
65	POL	Siekierki	622	1137	91	19	1	110	25	4.33
66	ESP	Alcudia	510	0	59	20	1	78	24	3.19
67	CZE	Pocerady	1000	100	33	106	1	139	52	2.70
68	ROM	Brasov	100	0	67	13	0	80	20	3.94
69	FRA	Le Havre	1415	0	85	80	1	164	84	1.95
70	POL	Lagisza	840	217	73	20	0	93	38	2.44
71	GRC	Ptolemais	620	0	19	6	2	23	52	0.45
72	GBR	Kilroot	390	573	95	24	1	118	34	3.41
73	ITA	Sicilia	1388	0	84	38	1	121	66	1.83
74	ITA	Brindisi Sud	2640	0	56	23	1	78	75	1.03
75	DEU	Marl	484	0	51	109	4	156	17	9.20
76	BGR	Republica I	130	264	47	9	0	56	21	2.62
77	DEU	Lippendorf	2110	600	137	58	1	194	65	2.98
78	FRA	Emile Huchet	1164	0	109	48	2	155	78	1.99
79	DEU	Boxberg	4668	0	110	83	2	191	187	1.02
80	DEU	Neurath	2100	0	57	117	2	172	78	2.20
81	FRA	Blenod/ P. Mousson	1000	0	100	46	1	145	62	2.33
82	ROM	Paroseni	300	95	57	13	0	70	25	2.83
83	CZE	Tusimice	1130	150	67	62	1	128	50	2.54
84	BEL	Ruien	255	0	120	38	1	157	30	5.25
85	ITA	Fusina	976	0	73	15	1	87	47	1.87
86	ROM	Giurgiu	150	357	63	5	0	68	19	3.60
87	FRA	Provence	13.7	0	87	53	2	138	5	26.42
88	POL	Adamow	600	0	72	20	2	90	47	1.91
89	ITA	Porto Tolle	2640	0	86	21	2	105	133	0.79
90	BGR	Svishtov	120	270	38	11	0	48	22	2.24
91	GRC	Aliveri	300	0	23	1	0	24	23	1.03
92	ESP	Cercs	175	0	59	10	0	68	22	3.07
93	DEU	Gelsenk./ Schloven	1344	230	62	38	0	99	113	0.88
94	HUN	Banhida	100	12	77	4	0	80	21	3.78
95	POL	Opole Works	1491	0	28	42	0	70	92	0.75
96	SVN	Sostanj	745	0	48	56	2	102	45	2.30
97	GRC	Rhodes	233.8	0	12	6	0	18	18	0.98
98	ROM	Suceava	100	280	58	1	0	59	17	3.55
99	ITA	Genova	295	0	69	24	1	91	30	3.08
100	POL	Krakow	1380	1396	65	15	0	80	79	1.01

7. Discussion

Limitations of analysis

It is again emphasized that there are many problems with the basic data for individual power stations used in this exercise and the volume of data is such that extensive checking is too time consuming for the scope of the project. Plainly, improvements to these data are an essential prerequisite for accurate and detailed analysis and plant-by-plant policy recommendations. It is, however, anticipated that the general conclusions reached are likely to be more robust as a result of errors for individual power stations canceling each other out when results are brought together.

BAT and costs

In this study the simple approach has been to apply constant levels of emission reduction to all sizes of plant of a given fuel type. In practice, however, BATECT would probably be specified in more complex detail such as in Directive 2001/80/EC of the European Parliament and of the Council, 23 October 2001, on the limitation of emissions of certain pollutants into the air from large combustion plants (European Parliament, 2001). This specifies Emission Limit Values (ELVs) of pollutants measured in pollution concentration (mg/Nm^3) rather than emission reduction, and ELVs vary according to parameters such plant size and age, fuel mix, and so forth.

Of particular importance is that in this Directive the ELVs become less stringent for smaller plant, presumably to account for the diseconomies of scale that bite as plant size (MW_{th}) decreases. As Figure 1 illustrates, the capital cost of ECT on a 50 MW_{th} plant might be five times the cost on a 500 MW_{th} plant. Figure 2 shows how capital costs might increase with removal rates. Therefore, the increase in capital costs with decreasing size may be partly offset by requiring lower removal rates (or less strict ELVs).

The result of this would be lower abatement costs for smaller plant sizes than assumed in this study, thus improving the ECT cost to health cost ratio for the smaller plant. A useful extension to this work would be to apply detailed specifications of BAT that are more closely related to plant parameters.

Emissions and abatement

The analysis shows that the total emissions and health costs are dominated by a few hundred large stations. However, there are many small stations and they are generally closer to population concentrations than large plant, and so emissions from them may be expected to have larger health impacts per unit emission. The spatial resolution of the atmospheric transport and transformation calculations, population distributions and health calculations is generally too coarse to account for this possibly disproportionate effect of small plant emissions.

General policy implications

The analysis shows that the economic benefits solely from reduced health damage of emission reduction exceed the costs for applying advanced emission control technologies to a large fraction of the fossil generating capacity in Europe.

Futhermore, apart from the regional air pollutants considered here, fossil power stations emit CO_2 and so meeting targets for CO_2 as well as National Emission Ceilings is made more difficult with fossil generation. Finally, fossil fuels are finite and so fossil generation increases problems of energy security (notably for gas-fired generation), and of course, of meeting the EU renewable energy targets. All of these factors will enhance the relative economics and other benefits of the alternative options of energy efficiency and renewable electricity generation, and so will add impetus to increasing the rate at which fossil generation is phased out.

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Annex 1. Emission control technology data

Annex 1.1. BATECT

Tables 19-22 below summarise some of the BATECT performance and cost data from a number of references. The data are from various years, countries and plant type. It is therefore difficult to express the costs on a comparable basis.

Table 19. FGD data: coal.

	TECHNICAL					CAPITAL						OPERATION AND MAINTENANCE			
			Removal			Original currency				2007		Capacity		Energy	
Reference	Type	Fuel	Ref	Max	GW_e		Low	Mid	High	€/kW_e	€/kW_{th}	€/kW_e/a	€/kW_{th}/a	€/MWh_e	€/MWh_{th}
DOE/EIA (2000)	FGD	Coal				\$/kW_e		195		235	89				
DOE/EIA (2007)	FGD	Coal			0.7	\$/kW_e		184		150	57				
DOE/EIA (2007)	FGD	Coal			0.5	\$/kW_e		223		182	69				
DOE/EIA (2007)	FGD	Coal			0.3	\$/kW_e		291		237	90				
DTI (2000)	FGD	Coal				£/kW_e	65	73	80	150	57			4.1	1.6
EC LCP BREF (2006)	FGD	Coal				€/kW_e	35	43	50	45	17	0.3	0.1	0.3	0.1
Energy Focus	FGD	Coal				£/kW_e	95	175	255	270	103	9.3	3.5		
Environment Canada (2005)	FGD	Coal	95%		0.3	C\$/kW_e		446		445	169	17.0	6.4	1.0	0.4
Hunwick (2003)	FGD	Coal				A\$/kW_e	100	120	140	78	30				
IEACCC (2000?)	FGD	Coal			0.7	\$/kW_e	100	113	125	117	45			1.2	0.5
IEACCCC (2006)	FGD	Coal		99%		€/kW_e	100	123	145	129	49				
IEACCCC (2007)	FGD	Coal	90%			€/kW_e	100	125	150	131	50				
Marchetti (2007)	FGD	Coal			0.8	\$/kW_e		320		261	99				
Rubin et al (2004)	FGD	Coal				\$/kW_e		130		157	60			5.4	2.1
Southern Company (2001)	FGD	Coal				\$/kW_e		170		169	64				
USEPA (2003b)	FGD	Coal			0.3	\$/kW_e	100	125	150	124	47	5.0	1.9		
Simple average										**180**	**68**	**7.9**	**3.0**	**2.4**	**0.9**

Table 20. SCR data: coal.

			TECHNICAL			CAPITAL						OPERATION AND MAINTENANCE			
			Removal				Original currency			2007		Capacity		Energy	
Reference	Type	Fuel	Ref	Max	GW_e		Low	Mid	High	€/kW_e	€/kW_{th}	€/kW_e/a	€/kW_{th}	€/MWh_e	€/MWh_{th}
Amar (2003)	SCR	Coal	90%		0.6	\$/kW_e	50	70	90	63	24				
DOE/EIA (2000)	SCR	Coal				\$/kW_e		72		87	33	7.7	2.9	0.5	0.2
DOE/EIA (2007)	SCR	Coal			0.7	\$/kW_e		95		78	29				
DOE/EIA (2007)	SCR	Coal			0.5	\$/kW_e		105		86	33				
DOE/EIA (2007)	SCR	Coal			0.3	\$/kW_e		120		98	37				
EC (2006)	SCR	Coal				€/kW_e	50	100		105	40				
Environment Canada (2005)	SCR	Coal	90%		0.3	C\$/kW_e		118		118	45	0.8	0.3	1.0	0.4
Foerter (2001)	SCR	Coal		95%		\$/kW_e	51	78	105	81	31				
Hunwick (2003)	SCR	Coal			0.7	A\$/kW_e		184		120	46				
IEACCCC (2006)	SCR	Coal				€/kW_e	50	100	150	105	40				
IEACCCC (2007)	SCR	Coal				\$/kW_e	100	125	150	97	37				
Lani et al (2006)	SCR	Coal				\$/kW_e		119		97	37	0.4	0.2	0.5	0.2
Marchetti (2007)	SCR	Coal			0.8	\$/kW_e	80	140	200	114	43				
Rubin et al (2004)	SCR	Coal	80%		0.8	\$/kW_e		65		78	30			0.7	0.3
Southern Company (2001)	SCR	Coal				\$/kW_e	60	90	120	89	34				
Staudt (?)	SCR	Coal	80%		0.8	\$/kW_e		70		73	28				
USEPA (2002b)	SCR	Coal				\$/kW_e	55	98	140	92	35				
Simple average		**Coal**								**99**	**38**	**3.0**	**1.1**	**0.7**	**0.3**

Table 21. SCR data: gas/oil.

			TECHNICAL			CAPITAL						OPERATION AND MAINTENANCE			
			Removal			Original currency				2007		Capacity		Energy	
Reference	Type	Fuel	Ref	Max	GW_e		Low	Mid	High	€/kW_e	€/kW_{th}	€/kW_e/a	€/kW_{th}	€/MWh_e	€/MWh_{th}
Amar (2003)	SCR	Gas				$/$kW_e$		35		33	13				
SCEPA (2004)	SCR	CCGT			0.5	$/$kW_e$		12.5		11	5				
SCEPA (2004)	SCR	GT			0.1	$/$kW_e$		28		24	9				
EC (2006)	SCR	Gas/oil				€/kW_e	10	30	50	35	13				
Environment Canada (2005)	SCR	Gas/oil	80%			C$/$kW_e$		40		40	15	1.2	0.5	1.0	0.4
Simple average		**Gas**								**28**	**11**	**1.2**	**0.5**	**1.0**	**0.4**

Table 22. NOx ECT data: gas, LNB and SCR+LNB combination.

			TECHNICAL			CAPITAL						OPERATION AND MAINTENANCE			
			Removal			Original currency				2007		Capacity		Energy	
Reference	Type	Fuel	Ref	Max	GWe		Low	Mid	High	€/kW_e	€/kW_{th}	€/kW_e/a	€/kW_{th}/a	€/MWh_e	€/MWh_{th}
DOE/EIA (2007)	ULNB	Coal	50%		0.8	$/$kW_e$		25		19	7	0.30	0.11	0.02	0.01
EC LCP BREF (2006)	LNB+OFA	Coal				€/kW_e		7		7	3				
IEACCCC (2006)	LNB	Coal				€/kW_e	20	30	40	32	12				
IEACCCC (2006)	LNB+OFA	Coal				€/kW_e	30	35	40	37	14				
Lani et al (2006)	LNB	Coal				$/$kW_e$		23		19	7	0.29	0.11	0.05	0.02
Lani et al (2006)	ULNB	Coal				$/$kW_e$	24	26	28	21	8	0.35	0.13	0.07	0.02
Simple average										**22**	**8**	**0.31**	**0.12**	**0.05**	**0.02**
	COMBINATION														
Simple average	**SCR+LNB**	**Coal/oil**	**95%**							**121**	**46**	**3.3**	**1.2**	**0.7**	**0.3**
Simple average	**SCR**	**Gas**	**90%**							**75**	**30**	**0.8**	**0.3**	**0.1**	**0.0**

Annex 1.2. Emission control technologies in primary databases

Those emission control processes present in the IEACCC and Platts databases are tabulated below with descriptions and acronyms. The descriptions are taken from the IEACCC and Platts databases. These data are for ECT installed over the past decades.

Table 23 sets out the basic emission control systems and combinations as found in the Platts and IEACCC databases. Before the underscore in the acronym are given the pollutants primarily controlled by the technology (N- NOx, S - SO_2, P – PMa).

The last columns give percentage reductions in emissions brought about by each process if it is applied to all of the combustion and combustion products in a station. It is emphasised that there is a great variation in these reduction figures in actual systems because of the specific details of plant design, fuel characteristics, etc. Note that particulate control equipment typically reduces particulate emission by over 99%. A small error in this fraction will result in a very large error in emission – 99% reduction will result in twice the emission of 99.5% reduction. Furthermore the reduction will vary with particle characteristics (size, physical and chemical properties). Typically, PMa control equipment removes a greater fraction of the large particles, leaving a large proportion of particles less than 10 microns, which are believed to be most injurious to human health.

Only the IEACCC and Platts primary databases give information about emission control equipment, and the data relate to each unit of a power station. The IEACCC power station database gives specific reductions for many emission control installations that are different from the typical figures. Where such specific data are not provided, the default data in Table 23 are assumed.

Table 23. Emission control systems.

Acronym	Description	NOx Rem	SO_2 Rem	PMa Rem
N_BOO	burners out of service [BOOS]	20%		
N_BOO_FGR	burners out of service [BOOS]; flue gas recirculation [FGR]	20%		
N_BOO_OFA	burners out of service [BOOS]; overfire air [OFA]	20%		
N_Com	unspecified combustion modifications for dry low NOx operation	20%		
N_Con	boiler controls tuning	45%		
N_FGR	flue gas recirculation [FGR]	30%		
N_FGR_UrI	Flue gas recirculation and urea injection	50%		
N_FGT	COS hydrolysis and MDEA scrubber	85%		
N_FGT_AcC	Activated-coke filter	85%		
N_FGT_MDE	COS hydrolysis and MDEA scrubber	85%		
N_FGT_SCR	selective catalytic reduction [SCR]	80%		
N_FGT_SCR_Oxi	OXI catalyst (NOx control)	80%		
N_FGT_SCR_SNR	SCR/selective non-catalytic reduction	80%		
N_FGT_SCR_WaI	Selective catalytic reduction/water injection	80%		
N_FGT_SNR	selective non-catalytic reduction [SNCR]	50%		
N_FGT_SNR_OFA	Selective non-catalytic reduction/overfire air	60%		
N_FGT_SNR_Reb	SNCR/gas reburn	60%		
N_FGT_SOLONOX	SoLoNox NOx control methodology	20%		
N_Inj_Amm	Ammonia injection	90%		
N_ISt	steam injection	20%		
N_ISt_SCR	Steam injection and SCR	70%		
N_IWa	Water injection	20%		
N_IWa_SCR	Water injection plus SCR	70%		
N_LNB	Dry low NOx burners	50%		
N_LNB_DLE	DLE low-NOx combustor	40%		
N_LNB_EV	Advanced environmental votex burners	40%		
N_LNB_EV_SCR	EV low-NOx burners plus SCR	40%		
N_LNB_FGR	Flue gas recirculation and low NOx burners	30%		
N_LNB_FGR_OFA	flue gas recirculation [FGR]; low NOx burners [LNB]; overfire air [OFA]	30%		
N_LNB_FGR_StC	flue gas recirculation [FGR]; low NOx burners [LNB]; two stage combustion [SC]	30%		
N_LNB_Hyb	Hybrid low-NOx burners	30%		
N_LNB_IWa	Low-NOx burners/water injection	30%		
N_LNB_Lea	LeaNOx combustion control system	30%		
N_LNB_OFA	Close-coupled overfire air	42%		
N_LNB_OFA_Cmo	Overfire air/combustion modifications	50%		
N_LNB_OFA_FGR	flue gas recirculation [FGR]; overfire air [OFA]	50%		
N_LNB_OFA_Reb	low-NOx cell burners; natural gas reburning; overfire air [OFA]	50%		
N_LNB_OFA_Sta	lowNOx burner; staged combustion [SC]; overfire air [OFA]	50%		
N_LNB_Ope	operational optimization	50%		
N_LNB_Reb	low NOx burners [LNB]; reburning [natural gas]	50%		
N_LNB_SCR	Dry low NOx combustors plus SCR	85%		
N_LNB_Solonox	SoLoNox lean pre-mixed combustion	85%		
N_LNB_St2	Two-stage combustion/lo-NOx burners	30%		
N_LNB_StC	Low NOx burners/staged combustion	30%		

Table 23. Emission control systems (continued).

Acronym	Description	NOx Rem	SO_2 Rem	PMa rem
N_St2	Two-stage combustion	30%		
N_St2_FGR	Two-stage combustion/flue-gas recirculation	40%		
N_StC	staged combustion [SC]	30%		
N_StC_OFA	staged combustion [SC]; overfire air [OFA]	40%		
N_StC_SCR	Staged combustion/SCR	85%		
N_StC_SNR	Staged combustion/SNCR	85%		
N_The	Thermal DeNox system	40%		
N_Unsp	Unspecified NOX removal equipment	40%		
N_Xon	Xonon catalytic combustion system	40%		
P_Bag	fabric filter [baghouse]			99.5%
P_Bag_Ven_Cyc	fabric filter [baghouse]; wet particulate scrubber [venturi]; mechanical collector [cyclone]			99.5%
P_Cyc	mechanical collector [cyclone]			99.5%
P_Cyc_Bag	fabric filter [baghouse]; mechanical collector [cyclone]			99.5%
P_Cyc_Fil	mechanical collector [cyclone]; ceramic filter			99.5%
P_ESP	Cold side ESP			99.5%
P_ESP_Bag	Baghouse/hot-side ESP			99.5%
P_ESP_Cyc	Combination particulate control (usually ESP preceded by multiclones or cyclone collector)			99.5%
P_ESP_Scb	ESP/scrubber			99.5%
P_ESP_Ven	electrostatic precipitator [ESP]; wet particulate scrubber [venturi]			99.5%
P_FGT	Semi-wet flue-gas cleaning			99.5%
P_Fil	hot gas filter			99.5%
P_Fil_Cer	ceramic filter			99.5%
P_Mec	Mechanical particulate control device			99.5%
P_N/A	Not applicable			
P_None	None			
P_Scb	Particulate scrubber			99.5%
P_Ven	Venturi particulate scrubber			99.5%
P_Ven_Fil	ceramic candle filters and Venturi scrubber			99.5%
S_FGD	system unknown		85%	
S_FGD_Alk	Double alkali FGD scrubber		85%	
S_FGD_Amm	Ammonia FGD scrubber		85%	
S_FGD_Cal	Calcium hydroxide injection FGD scrubber		85%	
S_FGD_Cir	Circulating-bed FGD scrubber		85%	
S_FGD_HCi_Dry	HCl flue-gas scrubber		85%	
S_FGD_Lst			85%	
S_FGD_Mag	Magnesium oxide FGD scrubber		85%	
S_FGD_MDE	MDEA reactor/COS hydrolysis		85%	
S_FGD_NOXSO	Noxso Corp or NOXSO process		85%	
S_FGD_Reg	regenerable, sodium sulfite		85%	
S_FGD_Reg_Mag	regenerable, magnesium oxide		85%	
S_FGD_SpD	Dry aqueous carbonate FGD scrubber		80%	
S_FGD_SpD_LIFAC			80%	
S_FGD_SpD_Lim	Dry lime FGD scrubber		80%	
S_FGD_SpD_SoC	Dry sodium carbonate scrubber		80%	

Table 22. Emission control systems (continued).

Acronym	Description	NOx Rem	SO_2 Rem	PMa rem
S_FGD_WeL	Wellman-Lord FGD scrubber		90%	
S_FGD_Wet	wet scrubber		90%	
S_FGD_Wet_CaC	Wet calcium carbonate FGD scrubber		90%	
S_FGD_Wet_Car	Wet carbide sludge FGD scrubber		90%	
S_FGD_Wet_Lim	Semidry lime FGD system		90%	
S_FGD_Wet_Lst	Wet limestone FGD scrubber		90%	
S_FGD_Wet_Sod	Wet sodium carbonate scrubber		90%	
S_Inj_Lim	Lime injection		50%	
S_Inj_Lst	Limestone injection		50%	
S_Inj_Sor	sorbent injection		50%	
SN_FGT_AcC	combined SO_2/NOx; activated carbon	60%	80%	
SN_FGT_Ele	combined SO_2/NOx; electron beam irradiation	60%	80%	
SN_FGT_Inj	combined SO_2/NOx; duct sorbent injection	60%	80%	
SN_FGT_NOXSO	Noxso Corp or NOXSO process	60%	80%	
SN_FGT_SCR	combined SO_2/NOx; catalytic	60%	80%	
SN_FGT_SNOx	Snox low NOX equipment	60%	80%	
SNP_Cat		60%	80%	99.5%
SNP_FBC	primary measure in CFBC	60%	85%	20%
SNP_FBC_Atm	Atmospheric circulating fluidized bed boiler	60%	85%	20%
SNP_FBC_Bub	Bubbling fluidized bed	60%	85%	20%
SNP_FBC_FGD_SpD	primary measure in CFBC, spray dry scrubber	40%	90%	20%
SNP_FBC_FGD_Wet	primary measure in CFBC, wet scrubber	40%	90%	20%
SNP_FBC_Pre	Pressurized fluidized-bed combustor	40%	90%	20%
SNP_FGD_SCR	combined SO_2/NOx/particulates, catalytic	90%	90%	99.5%

Annex 2.
Largest emitters, all countries

Table 11. All stations: Largest SO_2 emitters, pp. 58-59.

Table 12. All stations: Largest NOx emitters, pp. 60-61.

In the listings of individual power stations, this formatting has been applied to each power station row:

- **bold** signifies power stations with matched EPER (2004) emissions, but matching may be incorrect;
- *italic* signifies power stations which should have EPER emissions but no match was found because of matching error or because there is no entry in the EPER.
- Standard formatting is applied to power stations in countries not included in the EPER 2004 data collection.

Table 11. All stations: Largest SO_2 emitters.

	Cou	Plant	MWe	Fuel	Ash rem.	ECT	Rem.	Base kt	Red.	Emit post BAT kt	Euro/t
1	BGR	Maritsa II	1450	Coal	30%	FGD	40%	332	59%	8	169
2	ESP	Puentes	1400	Coal	30%		30%	312	69%	6	229
3	UKR	Krivoy Rog	3000	Coal	5%		5%	284	93%	6	611
4	UKR	Burshytn	2400	Coal	5%		5%	277	93%	6	465
5	UKR	Lodyzhinsk	1800	Coal	5%		5%	239	93%	5	411
6	UKR	Zmiyev	2400	Coal	5%		5%	211	93%	4	642
7	GRC	Megalopolis A	1400	Coal	30%	FGD	52%	209	46%	6	167
8	UKR	Kurakhovka	1470	Coal	5%		5%	207	93%	4	400
9	UKR	Pridneprovsk	1800	Coal	5%		5%	172	93%	3	610
10	UKR	Zuev	1200	Coal	5%		5%	165	93%	3	393
11	ESP	Teruel	1050	Coal	5%	FGD	95%	163	3%	65	289
12	UKR	Starobeshev	1800	Coal	5%		5%	160	93%	3	607
13	TUR	Seyitomer	600	Coal	30%		30%	149	69%	3	190
14	RUS	Troitsk	2059	Coal	5%		5%	143	93%	3	706
15	RUS	Novocherkassk	2245	Coal	5%		5%	143	93%	3	771
16	POL	Belchatow	4340	Coal	30%	FGD	72%	140	27%	7	1069
17	UKR	Uglegorsk	1200	Coal	5%		5%	127	93%	3	512
18	UKR	Kiev	1200	Coal	5%		5%	124	93%	2	521
19	UKR	Zaporozhye	1200	Coal	5%		5%	122	93%	2	506
20	UKR	Lugansk	1600	Coal	5%		5%	112	93%	2	717
21	BGR	Maritsa I	200	Coal	30%		30%	96	69%	2	163
22	POL	Patnow	1200	Coal	30%		30%	88	69%	2	655
23	RUS	Ryazan	1200	Coal	5%		27%	83	71%	2	525
24	RUS	Cherepetsk	1500	Coal	5%		5%	77	93%	2	971
25	GBR	Cottam	2008	Coal	5%		5%	67	93%	1	1432
26	ESP	Meirama	550	Coal	30%		30%	63	69%	1	345
27	ESP	Compostilla	1312	Coal	5%		27%	62	72%	2	1019
28	UKR	Slavyansk	800	Coal	5%		5%	62	93%	1	736
29	RUS	Ryazan	2800	Oil			0%	58	98%	1	2108
30	POL	Kozienice	2600	Coal	5%	FGD	85%	57	13%	7	997
31	PRT	Sines	1256	Coal	5%		5%	57	93%	1	1211
32	ESP	La Robla	620	Coal	5%		5%	57	93%	1	585
33	ROM	Craiova	240	Coal	30%		30%	56	69%	1	283
34	ROM	Turceni	2310	Coal	30%		30%	52	69%	1	1393
35	UKR	Uglegorsk	2400	Oil			0%	50	98%	1	2109
36	UKR	Zaporizhzhya	2400	Oil			0%	50	98%	1	2106
37	BLR	Lukoml	2400	Oil			0%	49	98%	1	2109
38	RUS	Cherepovets	630	Coal	5%		5%	48	93%	1	624
39	POL	Rybnik	1720	Coal	5%	Inj	48%	48	50%	2	1315
40	EST	Eesti	1610	Oilshale	10%		10%	47	88%	1	1423
41	BGR	Bobovdol	630	Coal	30%		30%	47	69%	1	530
42	RUS	Smolensk	630	X	5%		5%	47			
43	TUR	Kangal	450	Coal	30%	FGD	52%	46	46%	1	300
44	ROM	Drobeta	200	Coal	30%		30%	45	69%	1	340
45	HUN	Oroszlnany	235	Coal	5%		5%	45	93%	1	389
46	GBR	Eggborough	2065	Coal	5%		5%	44	93%	1	2135
47	RUS	Kostroma	600	Pea	10%		10%	43	88%	1	656
48	RUS	Pskov	630	Pea	10%		10%	43	88%	1	658
49	TUR	Tuncbilek	429	Coal	30%		30%	43	69%	1	336
50	SVK	Novaky	645	Coal	30%	FGD	30%	42	69%	1	495

Table 11 (continued). All stations: Largest SO_2 emitters.

	Cou	Plant	MWe	Fuel	Ash rem.	ECT	Rem.	Base kt	Red.	Emit post BAT kt	Euro/t
51	GBR	Ferrybridge	1470	Coal	5%		5%	41	93%	1	1809
52	GBR	Longannet	2400	Coal	5%		5%	41	93%	1	2814
53	GBR	Kingsnorth	1455	Coal	5%		5%	37	93%	1	1935
54	BGR	Varna	1260	Coal	5%		5%	37	93%	1	1444
55	GRC	Amyntaio	600	Coal	30%		30%	36	69%	1	723
56	GBR	West Burton	2000	Coal	5%	FGD	90%	36	8%	7	1677
57	GRC	Megalopolis B	0	X				34			
58	GBR	Aberthaw	1425	Coal	5%		5%	34	93%	1	1877
59	POL	Turow	1270	Coal	30%	Inj	58%	33	41%	1	2109
60	GBR	Rugeley	1000	Coal	5%		5%	32	93%	1	1604
61	SVN	Trbovlje	125	Coal	20%		20%	31	78%	1	373
62	GBR	Lynemouth	390	Coal	5%		5%	30	93%	1	830
63	GBR	Fiddlers Ferry	1926	Coal	5%		5%	30	93%	1	2948
64	TUR	Catalagzi	300	Coal	5%		5%	29	93%	1	596
65	POL	Jaworzno	1565	Coal	5%	FGD	5%	28	93%	1	2120
66	IRL	Moneypoint	915	Coal	5%		5%	27	93%	1	1686
67	GBR	Didcot	2000	Coal	5%		5%	27	93%	1	3000
68	GBR	Drax	3960	Coal	5%	FGD	90%	27	8%	5	4560
69	RUS	Moscow/ 22	1325	Coal	5%		5%	27	93%	1	2130
70	UKR	Starobeshev	1200	Oil			0%	26	98%	1	2103
71	ESP	Almeria	1100	Coal	5%	FGD	94%	26	4%	8	1038
72	TUR	Afsin Elbistan	1376	Coal	30%	FGD	96%	25	2%	10	2442
73	ESP	Velilla	0	X				25			
74	UKR	Kiev	1200	Oil			0%	25	98%	0	1874
75	POL	Kosciuszko	1800	Coal	5%	FGD	90%	24	8%	5	1800
76	ESP	Abono	903	Coal	5%		5%	24	93%	0	1921
77	ARM	Hrazdan	1110	Oil			0%	23	98%	0	2118
78	GBR	Ironbridge	1000	Coal	5%		5%	22	93%	0	2145
79	RUS	Moscow/ Kashira	900	Coal	5%		5%	22	93%	0	1664
80	BGR	Maritsa III	840	Coal	30%	FGD	93%	22	6%	4	1038
81	POL	Ostroleka	676	Coal	5%		5%	22	93%	0	1247
82	ESP	Guardo	498	Coal	5%		5%	22	93%	0	1089
83	RUS	Pervomoisk	270	Coal	5%		5%	21	93%	0	834
84	GBR	Cockenzie	1200	Coal	5%		5%	21	93%	0	2477
85	RUS	Severodvinsk	189	Coal	5%		5%	21	93%	0	741
86	POL	Konin	220	Coal	30%	FGD	76%	21	23%	1	1128
87	DEU	Jänschwalde	3000	Coal	30%	FGD	96%	20	2%	8	6463
88	CYP	Dhekelia	360	Oil			0%	20	98%	0	747
89	ROM	Govora	100	Coal	30%		30%	20	69%	0	576
90	UKR	Dobrotvorsk	300	Coal	5%		50%	20	48%	1	778
91	GRC	Lavrio	720	Gas			0%	20	0%	20	
92	PRT	Pego	628	Coal	5%		5%	19	93%	0	1580
93	ESP	Narcea	569	Coal	5%		5%	19	93%	0	1670
94	POL	Skawina	580	Coal	5%	FGD	13%	19	85%	0	1511
95	ROM	Brasov	100	Coal	30%		30%	19	69%	0	620
96	ESP	Anllares	350	Coal	5%		5%	19	93%	0	1167
97	ESP	Soto De Ribera	672	Coal	5%		5%	18	93%	0	1855
98	BGR	Republica I	130	Coal	5%		5%	18	93%	0	737
99	ROM	Giurgiu	150	Coal	30%		30%	18	69%	0	632
100	HUN	Matra	812	Coal	30%	FGD	80%	18	18%	1	1500

Table 12. All stations: Largest NOx emitters.

	Cou	Plant	MWe	Fuel	Base kt	ECT	Rem.	BAT Red kt	Emit post BAT kt	Euro/t
1	UKR	Krivoy Rog	3000	Coal	115			108	7	1022
2	UKR	Burshytn	2400	Coal	87			81	5	1010
3	UKR	Zmiyev	2400	Coal	84			79	5	1095
4	UKR	Pridneprovsk	1800	Coal	71			67	4	1001
5	UKR	Lodyzhinsk	1800	Coal	62			58	4	1072
6	RUS	Novocherkassk	2245	Coal	61			57	4	1237
7	**GBR**	**Drax**	**3960**	**Coal**	**58**	**Boi**	**50%**	51	7	1838
8	UKR	Kurakhovka	1470	Coal	58			54	3	977
9	UKR	Starobeshev	1800	Coal	55			51	3	1212
10	TUR	Afsin Elbistan	1376	Coal	54			51	3	944
11	UKR	Zuev	1200	Coal	46			44	3	947
12	UKR	Uglegorsk	1200	Coal	46			43	3	960
13	RUS	Troitsk	2059	Coal	45			43	3	1540
14	UKR	Kiev	1200	Coal	44			41	3	1002
15	**POL**	**Belchatow**	**4340**	**Coal**	**40**			38	2	3918
16	BGR	Maritsa II	1450	Coal	39			37	2	1247
17	UKR	Lugansk	1600	Coal	38			36	2	1442
18	UKR	Zaporozhye	1200	Coal	38			36	2	1104
19	**ESP**	**Compostilla**	**1312**	**Coal**	**35**			33	2	1391
20	TUR	Soma	990	Coal	34			32	2	1064
21	**ESP**	**Teruel**	**1050**	**Coal**	**31**			30	2	1252
22	RUS	Cherepetsk	1500	Coal	31			29	2	1669
23	UKR	Slavyansk	800	Coal	25			24	2	1219
24	TUR	Yatagan	630	Coal	25			23	1	942
25	RUS	Ryazan	2800	Oil	25			23	2	2073
26	**GBR**	**Aberthaw**	**1425**	**Coal**	**24**			23	1	1791
27	TUR	Kemerkoy	630	Coal	24			23	1	934
28	**PRT**	**Sines**	**1256**	**Coal**	**23**	**Boi**	**42%**	21	2	1643
29	**GBR**	**Ratcliffe**	**2000**	**Coal**	**23**	**Boi**	**50%**	20	3	2170
30	**GBR**	**West Burton**	**2000**	**Coal**	**23**	**Boi**	**42%**	20	2	2464
31	BGR	Maritsa III	840	Coal	23			21	1	1247
32	**ESP**	**La Robla**	**620**	**Coal**	**23**			21	1	1007
33	TUR	Seyitomer	600	Coal	22			21	1	994
34	**GBR**	**Cottam**	**2008**	**Coal**	**22**	**Boi**	**50%**	19	3	2227
35	**GRC**	**Dimitrios**	**1570**	**Coal**	**22**	**Boi**	**50%**	19	3	1801
36	UKR	Uglegorsk	2400	Oil	22			20	2	2073
37	UKR	Zaporizhzhya	2400	Oil	21			20	2	2071
38	**ESP**	**Velilla**	**0**	**X**	**21**					
39	BLR	Lukoml	2400	Oil	21			19	2	2073
40	**GBR**	**Kingsnorth**	**1455**	**Coal**	**20**	**Boi**	**42%**	18	2	1878
41	**IRL**	**Moneypoint**	**915**	**Coal**	**20**	**Boi**	**50%**	18	2	1175
42	**GRC**	**Kardia**	**1200**	**Coal**	**20**			19	1	2040
43	**GBR**	**Ferrybridge**	**1470**	**Coal**	**20**	**Boi**	**50%**	17	2	1912
44	ROM	Turceni	2310	Coal	20			19	1	3193
45	**GBR**	**Longannet**	**2400**	**Coal**	**19**	**Boi**	**50%**	17	2	2930
46	**ESP**	**Puentes**	**1400**	**Coal**	**19**			18	1	2873
47	**POL**	**Kozienice**	**2600**	**Coal**	**19**			18	1	4169
48	RUS	Ryazan	1200	Coal	19			18	1	1882
49	**GBR**	**Eggborough**	**2065**	**Coal**	**19**	**Boi**	**50%**	17	2	2421
50	**POL**	**Rybnik**	**1720**	**Coal**	**19**	**Boi**	**42%**	17	2	2427

Table 12 (continued). All stations: Largest NOx emitters.

	Cou	Plant	MWe	Fuel	Base kt	ECT	Rem.	BAT Red kt	Emit post BAT kt	Euro/t
51	**ESP**	**Abono**	**903**	**Coal**	**17**	**Boi**	**50%**	15	2	1346
52	**DEU**	**Jänschwalde**	**3000**	**Coal**	**17**	**Boi**	**42%**	16	2	5159
53	**DEU**	**Marl**	**484**	**Coal**	**16**	**SCR**	**80%**	11	5	525
54	TUR	Yenikoy	420	Coal	16			15	1	969
55	**ESP**	**Anllares**	**350**	**Coal**	**16**			15	1	887
56	**CZE**	**Prunerov**	**1490**	**Coal**	**16**			15	1	3070
57	RUS	Cherepovets	630	Coal	16			15	1	1319
58	**CZE**	**Pocerady**	**1000**	**Coal**	**16**			15	1	2172
59	**ESP**	**Almeria**	**1100**	**Coal**	**15**	**Boi**	**50%**	13	2	1562
60	BGR	Varna	1260	Coal	15			14	1	2482
61	**GBR**	**Didcot**	**2000**	**Coal**	**15**	**Boi**	**50%**	13	2	2583
62	**DEU**	**Frimmersdorf**	**2400**	**Coal**	**15**		**50%**	14	1	6780
63	**DEU**	**Eschweiler**	**0**	**X**	**14**					
64	**POL**	**Turow**	**1270**	**Coal**	**14**			13	1	4258
65	RUS	Kostroma	600	Pea	14			13	1	1440
66	**GBR**	**Tilbury**	**700**	**Coal**	**14**			13	1	1907
67	RUS	Pskov	630	Pea	14			13	1	1444
68	**GBR**	**Fiddlers Ferry**	**1926**	**Coal**	**14**	**Boi**	**42%**	12	1	3369
69	BGR	Bobovdol	630	Coal	13			13	1	1513
70	**DEU**	**Neurath**	**2100**	**Coal**	**13**	**Boi**	**30%**	12	1	3827
71	UKR	Burshytn	2400	Gas	13			12	1	3056
72	RUS	Novocherkassk	2400	Gas	13			12	1	3053
73	RUS	Stavropol Sdeps	2400	Gas	12			11	1	3053
74	**ESP**	**Narcea**	**569**	**Coal**	**12**			11	1	1741
75	**GBR**	**Cockenzie**	**1200**	**Coal**	**12**			11	1	2992
76	RUS	Moscow/ 22	1325	Coal	12			11	1	3260
77	**POL**	**Opole Works**	**1492**	**Coal**	**12**	**Boi**	**42%**	11	1	2677
78	*ESP*	*Guardo*	*498*	*Coal*	*12*			11	1	1345
79	UKR	Dobrotvorsk	300	Coal	12			11	1	1043
80	**POL**	**Kosciuszko**	**1800**	**Coal**	**11**	**Boi**	**42%**	10	1	3888
81	**ESP**	**Soto De Ribera**	**672**	**Coal**	**11**			11	1	2024
82	UKR	Starobeshev	1200	Oil	11			10	1	2068
83	**FRA**	**Le Havre**	**1415**	**Coal**	**11**			10	1	3795
84	RUS	Moscow/ Kashira	900	Coal	11			10	1	2352
85	UKR	Kiev	1200	Oil	11			10	1	1745
86	**POL**	**Patnow**	**1200**	**Coal**	**11**			10	1	4324
87	**ESP**	**Meirama**	**550**	**Coal**	**11**			10	1	1667
88	ROM	Craiova	240	Coal	11			10	1	1053
89	**PRT**	**Pego**	**628**	**Coal**	**10**		**50%**	10	1	1940
90	ARM	Hrazdan	1110	Oil	10			9	1	2082
91	RUS	Moscow/ 26	1910	Gas	10			9	1	2989
92	**ITA**	**Brindisi Sud**	**2640**	**Coal**	**10**	**Boi/SCR**	**88%**	4	6	7589
93	BGR	Maritsa I	200	Coal	10			9	1	1103
94	**POL**	**Jaworzno**	**1565**	**Coal**	**10**	**Boi**	**50%**	9	1	2744
95	**DEU**	**Boxberg**	**4668**	**Coal**	**10**	**Boi**	**50%**	9	1	10197
96	**FRA**	**Vazzio**	**160**	**Oil**	**10**			9	1	689
97	**DEU**	**Gelsenk./ Schloven**	**1344**	**Coal**	**10**	**Boi/SCR**	**90%**	4	6	11148
98	**GBR**	**Rugeley**	**1000**	**Coal**	**10**	**Boi**	**50%**	9	1	2717
99	RUS	Pervomoisk	270	Coal	10			9	1	1155
100	RUS	Kirishi	1800	Gas	10			9	1	3053

The Swedish NGO Secretariat on Acid Rain

The essential aim of the secretariat is to promote awareness of the problems associated with air pollution, and thus, in part as a result of public pressure, to bring about the needed reductions in the emissions of air pollutants. The aim is to have those emissions eventually brought down to levels – the so-called critical loads – that the environment can tolerate without suffering damage.

In furtherance of these aims, the Secretariat:

- Keeps up observation of political trends and scientific developments.
- Acts as an information centre, primarily for European environmentalist organizations, but also for the media, authorities, and researchers.
- Produces information material.
- Supports environmentalist bodies in other countries in their work towards common ends.
- Participates in the lobbying and campaigning activities of European environmentalist organizations concerning European policy relating to air quality and climate change, as well as in meetings of the Convention on Long-range Transboundary Air Pollution and the UN Framework Convention on Climate Change.

The European Environmental Bureau (EEB)

The European Environmental Bureau is a federation of over 145 environmental citizens' organisations based in all 27 EU Member States and most candidate and potential candidate countries as well as in a few neighbouring countries. These organisations range from local and national, to European and international.

EEB's aim is to protect and improve Europe's environment and enable its citizens to play a part in achieving that goal, by promoting environmental policy integration and sustainable policies, particularly at EU level. Our office in Brussels was established in 1974 to provide a focal point for our members to monitor and respond to the EU's emerging environmental policy.

It has an information service, runs working groups of EEB members, produces position papers on topics that are, or should be, on the EU agenda, and represents members in discussions with the Commission, the European Parliament and the Council. EEB closely co-ordinate EU-oriented activities with national member organisations and also track the EU enlargement process and some pan-European issues.

Current levels of emissions of sulphur dioxide (SO_2) and nitrogen oxides (NO_x) from power plants generate very significant health and environmental damage across Europe.

This study demonstrates that by applying up-to-date emission control technologies, these emissions could come down drastically. By estimating the costs and health benefits of further emission reductions, this study highlights the potential for substantial benefits for the European population from continued action to reduce emissions of SO_2 and NO_x.

Application of advanced emission control technologies to the 100 most polluting plants in the EU27 could reduce annual emissions of SO_2 by 3.4 million tonnes and those of NO_x by 1.1 million tonnes. This would cut total EU27 emissions of SO_2 by approximately 40 per cent and emissions of NO_x by 10 per cent.

The average benefit-to-cost ratio for measures at these 100 most polluting plants is 3.4, i.e. the estimated health benefits are 3.4 times bigger than the estimated emission control costs. The focus of this report on health means that damage to ecosystems and buildings is not included in the estimated benefits.

Emissions from large industrial point sources are currently regulated by the EU directives on Integrated Pollution Prevention and Control (IPPC) and Large Combustion Plants (LCP), and in December 2007 the European Commission presented proposed draft legislation to revise these directives.

It is evident from this study that there is significant variation in the application of emission control technologies between different plants and different countries, and that improved application of Best Available Techniques (BAT) for reducing air pollutant emissions from large industrial point sources could contribute significantly to better air quality in Europe.