# A comparison of air emissions of thermal power plants in South Africa and 15 European countries

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***Abstract***
*Data recorded in the recently established European Pollutant Emission Register (EPER) is potentially useful for benchmarking of the environmental performance of industrial activity against European practice. Entries in the category of large power plants in the reporting year 2001 for 15 European Union (EU) countries were evaluated to estimate total and fuel specific emissions of $NO_x$, $SO_2$, particulate matter, and $CO_2$. Since the EPER data quality is unknown and since it records only absolute values for emissions and thus does not allow for an eco-efficiency analysis, environmental or sustainability reports made available online by a subset of the operators were sourced to compile a set of specific emissions (per kWh of electricity generated) for the major fossil fuel types, viz. natural gas, fuel oil, coal and lignite. With a few exceptions, notably for $PM_{10}$ for eight countries and $NO_x$ in one case, the large power plant data reported to the EPER is shown to be sufficiently representative of fossil-fuel based generation of electricity and is trustworthy. The fuel mix differs considerably, and together with the varying standard of pollution control technologies, this results in a wide variation in the combustion-related environmental burdens of the generated electricity. Emissions data for South African thermal electricity generation was sourced from Eskom's 2000 environmental report; in absolute terms they are the highest in this comparison, and in specific terms amongst the three highest per unit of electricity generated from coal.*

*Keywords: air pollution, electricity, pollutant register, power generation*

## 1 Introduction

True to the old adage that one cannot control what one does not measure, modern environmental legislation charges regulatory agencies with the compilation and maintenance of pollution inventories. Accurate and up-to-date data is needed to judge the success of policy aimed at reducing environmental and health damages, be it through incentives, taxation or regulation. In the context of pollution from industrial activity, a very good example of such an inventory is the recently established European Pollutant Emission Register, EPER (Http://eper.cec.eu.int/eper/), a statutory register to which member countries are obliged to report on a triannual basis. The first set of data was due by mid 2003 for the reporting year 2001 (± 1). One of the categories of plants on which data is to be reported is that of large power plants (> 50 $MW_{th}$). By interrogating this section of the EPER, it should be possible to get a fairly accurate picture of the total emissions arising from power generation, in each of the reporting countries. If this data can be confirmed as trustworthy, it should be possible to use it for environmental benchmarking purposes.

In the South African context, public and regulatory concern over air quality has received much attention with the introduction of the new Ambient Air Quality Bill. Even though there are already pockets of excellence of ambient air quality monitoring and modelling, much of the debate has suffered from speculative claims based on statistically unfounded grab sampling, and made in a climate characterised by the absence of a broadly understandable 'big picture'.

It is the purpose of this paper to put some perspective into this big picture by preparing a comparison of total and specific (per kWh) emissions of priority air pollutants and $CO_2$ from South African power generation with that to a range of European countries (representing northern, southern and eastern conditions). The comparison is novel in that it attempts to utilise the first complete European data set on thermal power generation (sourced from the EPER) for this purpose. It is recognised that the quality of the EPER data needs to be validated before it can be used for such a purpose – or indeed any other policy review purposes.

In the decade between the Earth Summit in Rio

de Janeiro and the World Summit on Sustainable Development in Johannesburg, many utility companies (including Eskom) have seriously engaged with their role in the environment-development dilemma, and have started to regularly report on their performance, generally in 'triple bottom-line' terms, often published on the Internet. It was hypothesised that if a sufficient sample of EPER data could be checked against information published in these reports, it should be possible to comment on the quality of the EPER inventory in the category of large combustion plants. Also, in order to calculate the specific emissions (per kWh generated) for the various fuels employed, further data is required on power produced and fuels used at individual reporting plants – information that is not published in the EPER. The attempts to validate the EPER data in the category of large combustion plants thus necessitated an extensive review of environmental and sustainability reports, both of individual power plants and of utility companies.

## 2 Method and data

Primary data for the study was taken from the online version of the EPER in the category of large power plants, for emissions of oxides of nitrogen, oxides of sulphur, particulate matter, and carbon dioxide. The data is available from the EPER both at individual facility level, and at country and European Union (EU) aggregation level. The facilities reported on are defined to be engaged in "electricity, steam and hot water supply in public and industrial facilities in various sectors". By inspection, it was attempted to verify that the bulk of the plants in this category for which data is reported are engaged in the generation of electricity. The countries which reported by mid 2003 included all of the former EU15 as well as Norway and Hungary. In the work reported here, Norway and Luxembourg were not considered – the latter because it has no large combustion facilities.

From the South African perspective, a comparison with EU accession countries other than Hungary might be of much interest, especially with Poland, which has a large lignite and coal-based thermal generation capacity, but these countries were not obliged to report for the 2001 reporting year. Interested readers are welcome to contact the author for tentative data for the three other countries of the Visegrad block (CZ, PL, SK), not reported in here. For the South African situation, total and specific emissions data of the four pollutants of interest were sourced from Eskom's environmental report for 2000 (Eskom, 2000).

Data for electricity production in each of the countries, according to four major energy source categories (thermal, hydroelectric, nuclear and 'geothermal, solar, wood, wind and waste') were sourced from the website of the Energy Information Administration of the US Department of Energy (EIA, 2002).

In order to estimate specific combustion emissions (i.e. per kWh of electric output) for the different fuel types in the various countries, information provided on the web by operators of such plants was sourced. Best sources were found to be the environmental reports of EMAS- or ISO14001-certified power plants, or the sustainability reports of power companies. In some cases, sufficient information was available on web-pages for individual power plants. The most important information needed was the quantity of electricity generated in the year in which emission data was reported, as well as the type of fuel used. In cases where the electric output was only available for a year close to the emissions reporting year, and where the plant was a base-load plant, this data was also used.

For some of the countries studied, however, data on electric output of a sufficient number of individual plants could not be found. Here the following procedure was used to estimate the electric output: for a plant studied in the ExternE National Implementation (European Commission, 1999), the amount of $CO_2$ emitted per kWh generated was sourced (1995 data), and from the $CO_2$ emissions reported for 2001, an estimate could thus be obtained of the electric output. This method of course would assume no change in thermal efficiency nor in the calorific value of the fuels used, but again was deemed sufficiently accurate to get a rough indication of specific emissions.

Having obtained specific emissions of the four pollutants for the major fuels thus studied (gas, oil, coal, lignite and peat), it was then possible to factor these up to total national emissions per fuel type (by multiplying by the total electricity generated from each fuel – see next paragraph), and then to add these up to get a coarse estimate of total emissions related to fossil-fuel based electricity generation in each of the countries.

To estimate the contribution of the main types of fuels to the conventional thermal category, a number of different methods were used. In some cases, data was found for the years considered. In other cases, the 1995 data from the National Implementation Reports was used (European Commission, 1999). When these had clearly changed and where only two main fuels are employed, their contributions were varied until the total $CO_2$ emissions (obtained by multiplying the contributed kWh by the fuel-specific $CO_2$ emissions) were in reasonable agreement with the total recorded in the EPER (this is referred to below as the "$CO_2$ method").

Finally, a check was made on the agreement between the electricity-related emissions thus obtained and the data reported for large power plants in the EPER. Discrepancies between the two

could be due to one of five reasons:

i) a significant contribution of small power plant (< 50 $MW_{th}$) to total electric output would mean that own estimates of total pollution would be higher than those reported in the EPER;
ii) incomplete reporting to the EPER would result in the same observation – but it should be possible to support this possibility by inspection of the data reporting for individual plants;
iii) some large power plant might be producing heat (in the form of steam or hot water) only, which would result in the EPER reported emissions being higher than those independently estimated;
iv) not all fuel types used in thermal plants were considered for all countries, notably biomass-based emissions were not considered, and small contributors were ignored – this would mean again that EPER quantities would be higher than those independently estimated; and
v) the sample of plants used for the various fuel types in the different countries might have been insufficiently representative, or the data obtained from the web insufficiently accurate.

## 3 Results

### *3.1 Total and specific emissions in the countries studied*

Table 1 shows the total emissions from large combustion facilities in the four categories of interest, as obtained from the EPER and Eskom, but converted from kg to ton or kiloton, and rounded. For all but three of the European countries, the bulk of the facilities reported on are primarily engaged in electricity generation. The exceptions were:

France, for which only 29 of 103 listed facilities generate electricity, whilst 40 produce steam and hot water, and 34 are associated with a range of other industries. However, 91% of the reported $NO_x$, 84% of the $SO_x$ and 90% of the $CO_2$ originate from the power plant in this set, of which, in turn the electricity generators assume ~90%. The analysis was thus continued.

Sweden, for which only 3 of 23 listed facilities are thermal electricity producers, accounting for less than a quarter of the total thermal electricity output, whilst 19 are heat suppliers, but with very inconsistent reporting of emissions. Sweden is thus excluded from the further analysis.

The UK, for which combustion on 72 oil and gas producing offshore platforms was included in the 214 facilities. These reported only on $NO_x$ and $CO_2$. The totals of the offshore emissions in these two categories were obtained (13% of $NO_x$ and 7% of $CO_2$) and subtracted from the reported totals to give the values shown in Table 1.

It must be noted that Table 1 is not proposed as a reliable emissions inventory – it merely summarises data as obtained, which still need to be validated. Nevertheless, South African total emissions are immediately noted to be the largest in all categories but $CO_2$. This is only partially explained by total generation as listed in Table 2, which ranks thermal generation activity in South Africa behind that in Germany, the UK and Italy.

**Table 1: Total emissions from large power plants as reported to the EPER (2001) and by Eskom (2000)**

| *Country* | *$NO_x$ (t)* | *$SO_x$ (t)* | *$PM_{10}$ (t)* | *$CO_2$ (kt)* | *Plants reporting* |
|---|---|---|---|---|---|
| Austria | 5 360 | 2 350 | 62 | 8 900 | 17 |
| Belgium | 31 300 | 30 500 | 618 | 18 600 | 24 |
| Denmark | 30 500 | 7 710 | n.d. | 20 800 | 23 |
| Finland | 38 800 | 34 100 | 1 349 | 23 000 | 52 |
| France | 90 800 | 101 900 | 3 013 | 31 200 | 103 |
| Germany | 221 200 | 202 500 | 7 779 | 314 200 | 189 |
| Greece | 84 050 | 330 100 | n.d. | 50 300 | 12 |
| Hungary | 29 400 | 276 000 | n.d. | 21 600 | 20 |
| Ireland | 40 100 | 73 300 | 1 308 | 17 700 | 13 |
| Italy | 161 500 | 322 600 | 1 432 | 132 500 | 118 |
| Netherlands | 31 200 | 9 440 | 236 | 35 500 | 19 |
| Portugal | 45 600 | 124 900 | 3 329 | 17 800 | 8 |
| Spain | 651 500 | 937 600 | 29 325 | 94 100 | 59 |
| Sweden | 2 200 | 1 600 | n.d. | 3 600 | 23 |
| United Kingdom | 373 300 | 796 000 | 8 530 | 178 600 | 135 |
| South Africa | 674 000 | 1505 000 | 66 000 | 161 200 | n.a. |

*n.d. = no data; n.a. = not applicable*

**Table 2: Total electricity generation by type, 2001 TWh (EIA US DoE)**

| *Country* | *Conventional thermal* | *Hydroelectric* | *Nuclear* | *Geothermal, solar, wind, wood and waste* | *Total* |
|---|---|---|---|---|---|
| Austria | 17.33 | 41.42 | 0.00 | 2.05 | 60.79 |
| Belgium | 28.40 | 0.44 | 44.03 | 1.54 | 74.40 |
| Denmark | 29.29 | 0.03 | 0.00 | 6.09 | 35.41 |
| Finland | 27.93 | 13.07 | 21.66 | 8.32 | 70.98 |
| France | 43.95 | 73.71 | 400.90 | 3.54 | 522.10 |
| Germany | 342.39 | 20.25 | 162.64 | 22.63 | 547.90 |
| Greece | 47.04 | 2.08 | 0.00 | 0.89 | 50.01 |
| Hungary | 20.66 | 0.18 | 13.42 | 0.12 | 34.38 |
| Ireland | 22.19 | 0.59 | 0.00 | 0.41 | 23.19 |
| Italy | 203.01 | 46.34 | 0.00 | 8.66 | 258.01 |
| Netherlands | 80.01 | 0.12 | 3.78 | 4.31 | 88.21 |
| Portugal | 28.36 | 13.89 | 0.00 | 1.86 | 44.12 |
| Spain | 112.54 | 40.61 | 60.52 | 9.77 | 223.45 |
| Sweden | 6.02 | 78.35 | 65.75 | 3.80 | 153.92 |
| United Kingdom | 266.28 | 4.02 | 85.61 | 5.74 | 361.64 |
| South Africa | 186.84 | 2.06 | 10.72 | 0.00 | 199.62 |

### *3.2 Fuel specific emissions in the countries studied*

As laid out in the discussion of the method used to validate data, it was attempted to estimate specific emissions for each of the most commonly used fossil fuels, in each of the countries studied. To do this, the annual emission of a power station (as reported in the EPER or in a company report) was divided by its annual electric generation, and weighted averages were then calculated for a number of similar plants. In the following sections, results will be shown for those fuels of most interest in the South African context only, viz. coal and lignite. Gas, fuel oil and peat make up the remainder of fossil-based generation in Europe.

#### *a) Coal based electricity generation*

Table 3 reports the estimates for emissions of $NO_x$, $SO_x$, $PM_{10}$ and $CO_2$ per kWh of electricity generated from combustion of coal in each of the countries considered. South Africa's exceptionally high reliance on coal is well-known, and amongst the countries considered in this study is only rivalled by Poland (> 95 % from coal and lignite combined) and Greece (67% from lignite).

The values obtained (or adopted from previous work) for $CO_2$ emissions vary significantly. The Finnish plant studied in the 1995 study was noted to be one of the 'cleanest and most efficient coal-fired power stations in the world' with a thermal efficiency of 43.1% (HHV basis; European Commission, 1999). It is not reflective of the national average. The Italian number is based on data for a single facility and should be treated with caution, however, with coal being a less significant fuel in Italian power generation, it is deemed sufficiently accurate for the purposes of this study. The Spanish number is high, which might be due to the use of lignite in some power plants, which was not disaggregated here.

$NO_x$ and $SO_x$ values appear to fall into three broad camps: those with stringent pollution control, those with some pollution control, and those with very little pollution control. South African generation clearly falls into the latter category, having the highest $NO_x$ emissions per kWh of electricity generated from coal, and specific $SO_x$ and particulate emissions being amongst the three highest. (Note: the Spanish $SO_x$ number appears too high by about 50%. It is based on the numbers reported in the sustainability report of one of the large producers. The other power companies might be operating with significantly lower $SO_x$ emissions.)

#### *b) Lignite-based electricity generation*

A significant fraction of thermal electricity generation in Germany, the Visegrad block countries and in Greece is based on the use of lignite. This industry sector is included here only to demonstrate the difference in performance that can be achieved by the application of modern pollution control methods and equipment, even when an inferior fuel is used.

## 4 Validation

Similar tables for specific emissions were prepared for the other major fossil fuels used in European power generation, notably natural gas and fuel oil,

**Table 3: Estimated specific emissions from combustion of coal for power generation**

| *Country* | *$NO_x$ mg/kWh* | *$SO_x$ mg/kWh* | *$PM_{10}$ mg/kWh* | *$CO_2$ g/kWh* | *% of total generation* |
|---|---|---|---|---|---|
| Austria[2, 3] | 490 | 260 | 56 | 900 | 4 |
| Belgium[1, 4] | 2 530 | 3 162 | 341 | 920 | 14 |
| Denmark[2, 5] | 1 440 | 640 | (= DE?) | 900 | 27 |
| Finland[1, 6] | 1 400 | 1 080 | 61 | 770 | 30 |
| France[1,7] | 3 140 | 2 930 | 290 | 900 | 5 |
| Germany[8] | 560 | 840 | 34 | 945 | 24 |
| Hungary[15] | 2 600 | 18 500 | 1 180 | 1 100 | 38 |
| Ireland[1, 9] | 3 430 | 4 980 | 92 | 920 | 28 |
| Italy[10] | 860 | 1 890 | 93 | 800 | 9 |
| Netherlands[11] | 1 310 | 560 | 23 | 910 | 15 |
| Portugal[2, 12] | 2 260 | 4 160 | 180 | 900 | 26 |
| Spain[13] | 3 610 | 14 800 | 400 | 1060 | 38 |
| United Kingdom[14] | 2 440 | 7 460 | 110 | 950 | 34 |
| South Africa (rank) | 4 020 (1) | 8 970 (3) | 390 (3) | 960 | 94 |

***Notes:***

1. Value for $CO_2$ set equal to that in the ExternE National Implementation report (European Commission, 1999).
2. Value for $CO_2$ set equal to that reported in the ExternE National Implementation Report for France (no country-specific values in the National Implementation Report).
3. For only large coal-fired plants in Austria, fuel contribution by dividing estimated output by total generation.
4. Using company average numbers in Electrabel (2003), assigning all $SO_x$ to coal-fired stations.
5. For $NO_x$, $SO_x$ and $PM_{10}$ average performance of three Danish coal-fired stations.
6. For $NO_x$, $SO_x$ and $PM_{10}$ average performance of six Finnish coal-fired stations.
7. Based on totals for EDF plant (www.edf.fr/html/osge/edf_engagement_6.htm#locaux) divided by coal-based output estimated by "$CO_2$ method" applied to EDF.
8. Based on an analysis for five plants, supplementary data from STEAG (2001), www.saarenergie.de and www.rwe-power.com/generator.aspx/standorte/id=8580/standorte-home.html.
9. Values for only large coal-fired plants in Ireland, contribution estimated by dividing plant output by total.
10. Analysis of one Italian-coal fired plant only, deemed sufficient since coal only No. 3 fuel.
11. Analysis of three plants, $CO_2$ intensity from a single plant with known generation (Electrabel NL, 2002).
12. For only large coal-fired plants in Portugal.
13. Aggregate values for all coal-fired plants of one company (Endesa, 2003). The $SO_x$ number appears higher than the national average, by about a third. A value of 11000 seems more reasonable.
14. Analysis based on the performance of all coal-fired plants of Powergen (2000) aggregated with all coal-fired plants of Scottish and Southern Energy (2001). Fuel contribution estimated using "$CO_2$ approach" but to give only 90% of $CO_2$, taking into account the inclusion of oil and gas platforms in EPER dataset.
15. Data from CUEC (Rabl, 2004) for specific emissions but the value for $SO_x$ shown here calculated from EPER totals; $CO_2$ very uncertain; contribution of coal-based to total thermal estimated from specific $CO_2$ emissions of identifiable plant reporting to EPER.

but are not included here. It is well-known that natural gas based generation results in no particulate emissions and strongly reduces $SO_x$ emissions, $NO_x$ control remaining an issue. Fuel oil combustion, on the other hand, may result in significant emissions in all three of the categories considered here.

By multiplying the specific emissions estimated for each of the fossil fuels by the percentage of total generation and by the total generation as shown in Table 2, an independent estimate was obtained of total emissions from fossil-fuel based electricity generation in the 14 countries for which totals had earlier been obtained from the EPER (Table 1). As discussed in Section 2, this estimate should be reasonably close to the total emissions for large power plants reported in the EPER. Table 5 illustrates the differences between the two sets of data, by reporting the ratio of our aggregated values to the EPER reported values.

It must be noted that the results shown above for the specific emissions from the various fossil-fuelled combustion plants are in most cases approximations, resulting from sampling of a subset of the total number of plants. For most countries, this subset was enlarged randomly, depending on the availability of the necessary information on the Internet, until the aggregated emissions were deemed to be in reasonable agreement with the totals obtained

**Table 4: Estimated specific emissions from combustion of lignite and peat for power generation**

| *Country* | *$NO_x$ mg/kWh* | *$SO_x$ mg/kWh* | *$PM_{10}$ mg/kWh* | *$CO_2$ g/kWh* | *% of total generation* |
|---|---|---|---|---|---|
| Austria[1] | 618 | 1048 | 107 | 945 | 2 |
| Germany[2] | 715 | 430 | 26 | 1 060 | 27 |
| Greece[3] | 1768 | 8214 | n.a | 1 337 | 67 |

***Notes:***
1. Austrian value from the EMAS declaration of the only lignite-fired plant (Verbund, 2003).
2. Based on an analysis of 5 very large baseload plants, some uncertainty on generation statistics; supplementary data from www.rwepower.com/generator.aspx/standorte/id=8580/standorte-home.html.
3. All supplementary data from PPC S.A. (2002), covers all lignite-fired plants in Greece at level of individual plant.

**Table 5: Ratios of estimated emissions for all fossil-based electricity generation to reported emissions for large plants**

| *Country* | *$NO_x$ (kg)* | *$SO_x$ (kg)* | *$PM_{10}$ (kg)* | *$CO_2$ (t)* | *"$CO_2$ method"* |
|---|---|---|---|---|---|
| Austria | 0.91 | 1.11 | 4.62 | 1.00 | Yes |
| Belgium | 0.92 | 1.05 | 5.58 | 1.07 | No |
| Denmark | 0.95 | 1.39 | | 0.87 | No |
| Finland[1] | 0.90 | 1.11 | 0.64 | 0.98 | No |
| France | 1.27 | 0.88 | 2.83 | 1.12 | No |
| Germany[2] | 0.90 | 0.90 | 1.07 | 0.96 | No |
| Greece | 1.05 | 1.00 | | 0.99 | No |
| Hungary[3] | 1.46 | 2.10 | | 0.93 | Yes |
| Ireland | 1.15 | 1.01 | 2.10 | 1.08 | No |
| Italy | 0.93 | 1.05 | 6.07 | 0.97 | No |
| Netherlands[4] | 1.14 | 0.82 | 1.31 | 1.10 | Yes |
| Portugal | 1.07 | 1.08 | 1.02 | 1.03 | No |
| Spain | 0.47 | 1.34 | 1.13 | 1.00 | No |
| United Kingdom | 0.91 | 1.14 | 1.64 | 1.00 | Yes |

***Notes:***
1. No estimate could be found for $PM_{10}$ emissions from peat-fired plants in Finland.
2. For Germany, relative to EPER totals for the 160 power plants (heat and electricity) amongst the 189 facilities reported on; this set makes up 95% of $NO_x$, 93% of $SO_x$ and 96% of $CO_2$.
3. The Hungarian value for $SO_x$ reflects the result obtained by application of independent source data (Rabl, 2004) – not the value shown in Table 3.
4. In the case of the Netherlands, the attempt made to set the split between gas and coal-based generation so that estimated $CO_2$ emissions would agree with reported ones gave the result that the contribution of gas to total generation should be in excess of 80%, which appeared unreasonable. A historically more reasonable estimate of 75% was used – this needs to be checked against an independent source.

from the EPER (shown in Table 1). Table 5 needs to be carefully evaluated in order to determine to what extent this objective was achieved, and to what extent remaining differences between the two data sets are real.

**$CO_2$ agreement:** For the 10 countries where independent data could be found for the contribution of the various fuels to the thermally generated electricity total, in five cases, the difference between the independently estimated and the reported $CO_2$ emissions are within 3%, and in four other cases, between 7 and 15%. For Germany, the EPER total was adjusted downwards to account for power plant only, and the difference between the two data sets could be closed to < 5%. The 12% over-prediction for France was investigated further, and it appears that there is significant under-reporting on behalf of the independent power producers (IPP). Specific $CO_2$ emissions for the 15 Electricité de France (EDF) facilities come to 926 kg/kWh, whereas those of the 10 IPP come to only 257 kg/kWh, an unlikely result. For the other countries, however, the generally good agreement of $CO_2$ totals gives confi-

dence, especially in the numbers obtained for the contribution of the various fuels to the total.

**Cases of under-reported particulate matter:** It seems that $PM_{10}$ is not always reported well to the EPER. Some countries have not reported it at all (Denmark, Greece, Hungary and Sweden), whereas for others reporting seems to have been for some facilities only, resulting in a total that is significantly under-reported (notably in the cases of Austria, Belgium, France and Italy). As a first estimate, the missing $PM_{10}$ emissions for Denmark could be estimated from the coal fired generation facilities only using specific emission data for German coal-fired plants, and those for Greece from the oil and lignite generation facilities, using Italian data for specific emissions from oil-fired plants, and Spanish data for specific emissions from coal-fired plants.

**Discrepancies for $NO_x$:** The only major discrepancies between independently estimated and reported $NO_x$ arise in the cases of France, Hungary and Spain. In the French case, our over-estimate might have arisen from one of two sources: i) the $NO_x$ value for gas-fired plants as taken from the 1995 data-set (European Commission, 1999) might be too high, or ii) independent power producers could be lower in $NO_x$ than EDF whose numbers were used. For the Hungarian case, the discrepancy was merely noted and not followed up; EPER data will be used in the absence of a trustworthy independent validation. The Spanish case is significant, with the Spanish power industry being the largest $NO_x$ emitting one according to the EPER figures (as summarised in Table 1). It appears that this may be erroneous: one Spanish power station in the EPER has been identified where the $NO_x$ emission equals the $CO_2$ emission, at 362 000 tons per annum, which is clearly unreasonable. Correcting for this error would bring the ratio between the independently estimated and the reported $NO_x$ to a much better 1.06.

**Discrepancies for $SO_2$:** These are unsatisfactory for three countries (Denmark, the Netherlands and Spain), but less than 15% for the other nine countries. It is likely that the discrepancies arise in the first instance from unrepresentative samples in the various countries. Power plants either are equipped with desulphurisation or not, and when the balance is wrong in the sample of plants used to get an estimate of the fuel-specific $SO_x$ emission, the numbers obtained are likely to be in error. This is likely to be the case for the Spanish coal fuel cycle, where a

**Table 6: Revised[1] total emissions from thermal[2] power plants (2000/2001)**

| *Country* | *$NO_x$ (t)* | *$SO_x$ (t)* | *$PM_{10}$ (t)* | *$CO_2$ (kt)* |
|---|---|---|---|---|
| Austria | 5 360 | 2 350 | **280** | 8 868 |
| Belgium | 31 300 | 30 500 | **3 450** | 18 600 |
| Denmark | 30 500 | 7 710 | **320** | 20 800 |
| Finland | 38 800 | 34 100 | 1 350 | 23 000 |
| France[3, 4] | **115 100** | 101 900 | **8 500** | **35 000** |
| Germany | **210 400** | **187 900** | 7 780 | **302 900** |
| Greece | 84 050 | 330 100 | **14 000** | 50 300 |
| Hungary | 29 400 | 276 000 | **17 200** | 21 600 |
| Ireland | 40 100 | 73 300 | 1 310 | 17 700 |
| Italy | 161 500 | 322 600 | **8 700** | 132 500 |
| Netherlands | 31 200 | 9 440 | 240 | 35 500 |
| Portugal | 45 600 | 124 900 | 3 330 | 17 800 |
| Spain | **292 000** | 937 600 | 29 300 | 94 100 |
| United Kingdom | 373 300 | 796 000 | **14 000** | 178 600 |
| South Africa | 674 000 | 1 505 000 | 66 000 | 161 200 |

***Notes:***

1. Numbers in bold are those modified from those shown in Table 1 as a result of the validation process.
2. This represents reasonably accurately all thermal power plants for electricity generation, large and small, fossil and biomass, where the contributions of small plant and biomass-fuelled plants remain small, at most 10% in the case of Finland.
3. Totals for France and Germany explicitly also include large urban heating plants, although their contribution to the total in most cases seems to be of the order of 10% only.
4. Numbers for France are those estimated by aggregation of our own fuel-specific data, due to the suspected under-reporting of non-EDF facilities.

specific emission of 11000 g/kWh appears more likely than the value given in Table 3. Given the fairly good agreement between EPER and independent numbers for $CO_2$ and $NO_x$, it would appear that the EPER numbers for $SO_x$ should, in general, be trustworthy – even with non-uniform practices for reporting $SO_x$ from gas fired power stations.

As a result of this analysis, a revised emission inventory can now be proposed, representing total emissions for fossil-fuel based electricity generation in Europe. Table 6 shows this inventory, with numbers in bold amended from those in Table 1.

## 5 Discussion

As stated in the Introduction, it is the purpose of this paper to provide a benchmark for air emissions from South African thermal power plants with those in European countries, in order to provide an additional perspective on the ongoing air quality discussion in South Africa. With data from the European Pollutant Emission Register (EPER) now validated (and slightly adjusted in some cases), it is possible to present some comparisons.

The first result evident from Table 6 is that total emissions from thermal power generation in South Africa are higher than those in any of the European countries studied, in all categories but $CO_2$ where they are the 3rd largest. This should give rise to concerns as to possible impacts on ecosystems and human health, even if one acknowledges that pathways to, and characteristics of, potential receptors may be very different.

A possible explanation for the South African pollutant emissions being so large lies in the country's high reliance on coal as a fuel, which is much more difficult to burn cleanly than the other fossil fuels. This does explain, in part, the high total emissions in the South African case. However, as Figure 1 shows, it is both the high coal use intensity and the high specific emissions which combine to give this result. In contrast to this, Germany, which is also strongly reliant on coal and lignite, has mandated stringent emission controls and thus has very low specific and mid-range absolute emissions (except for $CO_2$).

Finally, in order to add yet another perspective to the discussion, it is useful to compare entire country electricity systems. By dividing total emissions from large power plants by the total electricity produced, a rough indication can be obtained of the specific air pollution loads of electricity generation in the various countries. It should be noted that it is this type of data (though not necessarily the values reported here) that is used in many environmental decision-making support tools, such as in life cycle assessment (LCA) databases.

As expected, the countries with significant nuclear and hydroelectric generating contributions have low specific emission of all pollutants (notably France, Austria and Sweden, though the latter is not shown here). On the other extreme, countries heavily reliant on fossil fuels, and with a relatively low degree of use of pollution control technology have specific emissions generally 10-20 times higher (notably the Southern and Eastern European countries Greece, Hungary, Portugal, Spain but also Ireland, the United Kingdom and South Africa). In between are countries with a reasonably equilibrated fuel mix and a high degree of use of modern pollution control technology (Belgium, Denmark, Finland, Germany and the Netherlands – the 'Northern European' block). Italy seems to be in a transition phase towards this last group.

## 6 Conclusion

An attempt was made to determine whether the data reported to the EPER for large combustion plants is reliable and representative of fossil-fuel based generation of electricity in Europe, and, by extension, whether it can be used in comparative studies. It was possible to construct rough estimates of the combustion related specific emissions (per kWh generated) for the major fossil fuel types in 14 of the 15 European countries studied, from the EPER data supplemented by environmental and production data published online by a subset of the operating companies. The EPER data in the category of large combustion plants was found generally representative of thermal electricity generation (with the exception of Sweden in general, $PM_{10}$ for seven countries, and $NO_x$ for Spain due to one erroneous entry). It is concluded that the corrected set shown in Table 6 can be used for policy-making and assessment, and that the fuel-related specific emission data obtained (e.g. those shown in Tables 3 and 4) are robust though not fully representative.

The comparison of thermal power plants in South Africa with that in Europe shows that the South African power industry emits more nitrous oxides, oxides of sulphur and particulates than are emitted by electricity generators in any of the 15 European countries studied. This is explained by the combination of two reasons:

i) the comparatively high specific emissions from coal-fired plants (here, South African stations perform at the worst level in Europe, alongside the Spanish, Greek and Hungarian industries); and
ii) the comparatively very large usage of coal for electricity generation in South Africa.

In interpreting these comparative emission inventories, care should be taken not to jump to conclusions with regard to environmental and human health impacts. Except for $CO_2$, the pathways of the emitted pollutants to potentially sensitive receptors are likely to be different, as will be key receptor characteristics, such as population density or exposure to other pollutants. Nevertheless, the

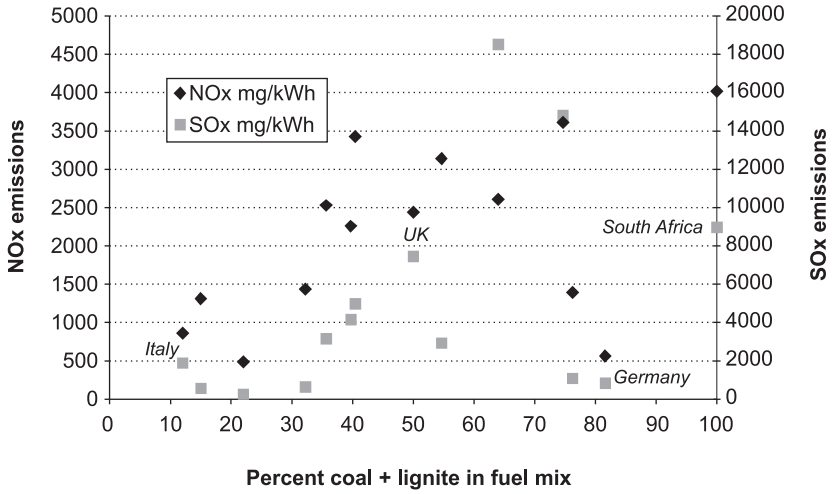


**Figure 1: Emissions performance of coal-fired plants in relation to coal use intensity (based on results of Tables 2 and 3)**

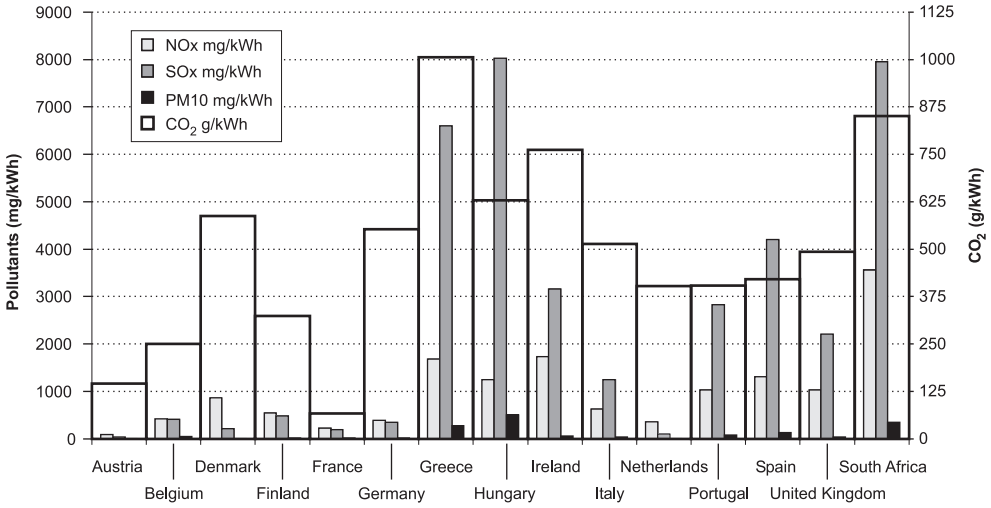


**Figure 2: Total emissions from large power plants divided by total electricity produced (based on Table 6 and Table 2)**

comparatively large emissions should give rise to concern for possible negative impacts on human and ecosystem health.

## Acknowledgements

The comments and critique of two anonymous referees is gratefully acknowledged, as is the support, encouragement and friendship of Ari Rabl of the *Ecole des Mines de Paris*.

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*Received 22 November 2004; revised 25 March 2005*