EN35 External costs of electricity production

Key message

The external costs that arise from the environmental impact of electricity production are significant in most EU-25 countries and reflect the dominance of fossil fuels in the generation mix. In the EU-25, the total external costs of electricity productions add to between 0.7 and above 2 % of the GDP in the year 2003, depending on the assumptions made for the external costs per unit of air pollutant and CO_2 emissions. Despite progress, these external costs are still not adequately reflected in energy prices. Consumers, producers and decision makers do not therefore get the accurate price signals that are necessary to reach decisions about how best to use resources.

Rationale

Electricity production causes substantial environmental and human health damages, which vary widely depending on how and where the electricity is generated. The damages caused are for the most part not integrated into the current pricing system and so represent external costs. The objective of the indicator is to assess the external costs associated with electricity production. When combined with information on environmental taxes and economic instruments, the indicator is relevant in assessing progress towards internalising external costs or 'getting the prices right'.

Fig. 1a: External costs of electricity production in EU-25, 1990 and 2003 - low estimate

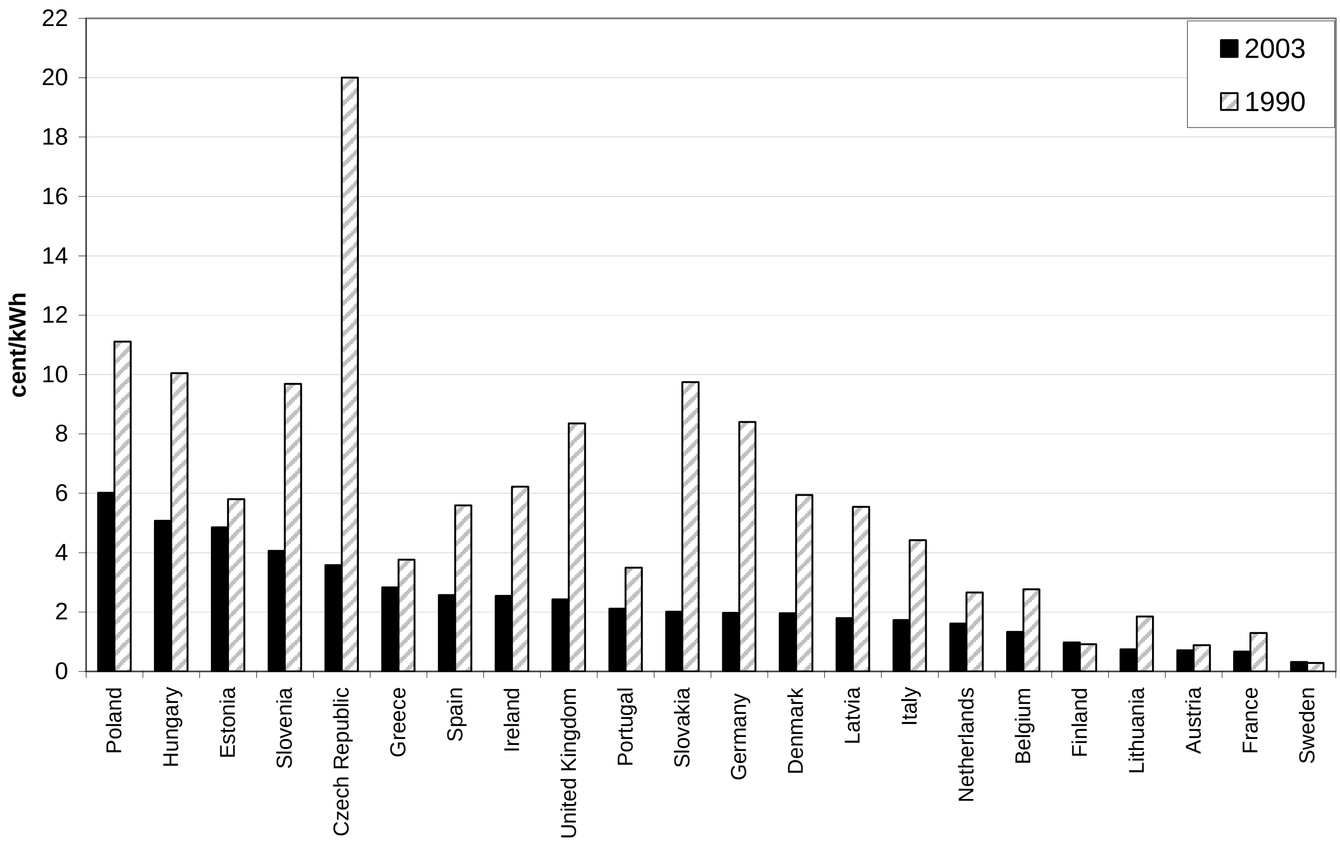
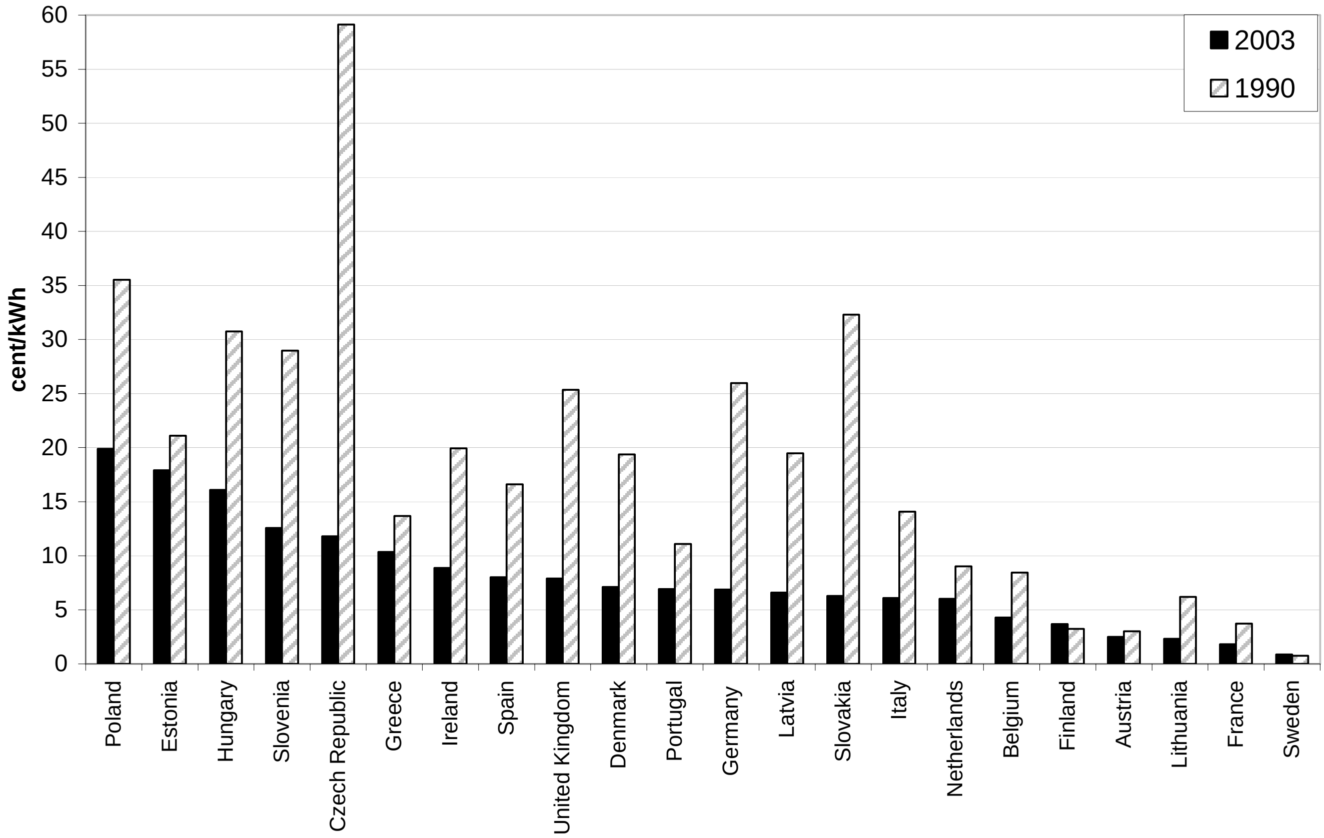


Fig. 1b: External costs of electricity production in EU-25, 1990 and 2003 - high estimate



Data source: ExternE-Pol (2005), CAFE, European Environment Agency/ETC, Eurostat

Note: The external costs in the above two figures are based upon the sum of three components associated with the production of electricity: climate change damage costs associated with emissions of CO_2; damage costs (such as impacts on health, crops etc) associated with other air pollutants (NOx, SO_2, NMVOCs, PM_{10}, NH_3), and other non-environmental social costs. The external costs for nuclear and climate change cover only a part of the total external costs.

Marginal damage cost factors (cost in € per tonne of pollutant) are taken from ExternE-Pol (2005) in the case of CO_2 (low estimate) and from CAFE (Clean Air for Europe programme) in the case of the other air pollutants. The external costs for CO_2 (high estimate) are taken from Watkiss et al. (2005). These are applied to the overall level of emissions by pollutant in each Member State in 1990 and 2003 to produce an overall damage cost in million Euro for that year. A complete data set for all emission types in this category is not available for Malta or Luxembourg so these countries have been excluded from the above graphs. Cyprus has been omitted due to the CAFE conclusion that marginal damage cost factors as a result of modelling work, for this country, were not considered sufficiently robust for inclusion in the final report.

The other non-environmental social costs are taken from ExternE-Pol (2005) and provide a eurocent/kWh external cost for different types of electricity technologies, which are multiplied by the quantity of electricity produced from each of these technologies, in each Member State, for 1990 and 2003 to produce a damage cost for that year in million euro. This overall cost is added to that associated with the emissions of CO_2 and other air pollutants and is then divided by the overall electricity production for that year in each Member State to produce an estimate of the external costs associated with each unit of electricity generation. Differences between the low and high estimate are mainly due to different methods of valuating changes in longevity. For further details on differences between ExternE-Pol and CAFE and between the CAFE low and high estimates see metadata section.

1. Indicator assessment

The external costs of electricity production have fallen considerably between 1990 and 2003 in all Member States (except for Finland and Sweden, where they increased slightly), despite rising electricity production. However, the external costs of electricity production for the EU-25 in 2003 still represent between 0.7 and 2.2 % of EU-25 GDP[1], depending on whether the low or high range of the damage costs are used. In 2003 the average external costs of electricity production in the EU-25 were between 2.0–6.5 EUR ct/kWh (1990: 5.6–17.5 EUR ct/kWh).

External costs for electricity are those that are not reflected in its price, but which society as a whole must bear. For example, damage to human health is caused by emissions of particulate matter (including both primary particulates and secondary aerosols). SO_2, NO_X and VOC emissions also lead to human health impacts (which are considered to be the largest externality) through the formation of secondary pollutants. NO_X and VOC emissions have health impacts through the formation of ozone. SO_2 and NOx emissions form secondary particulates in the atmosphere (which have similar effects to primary PM). There are

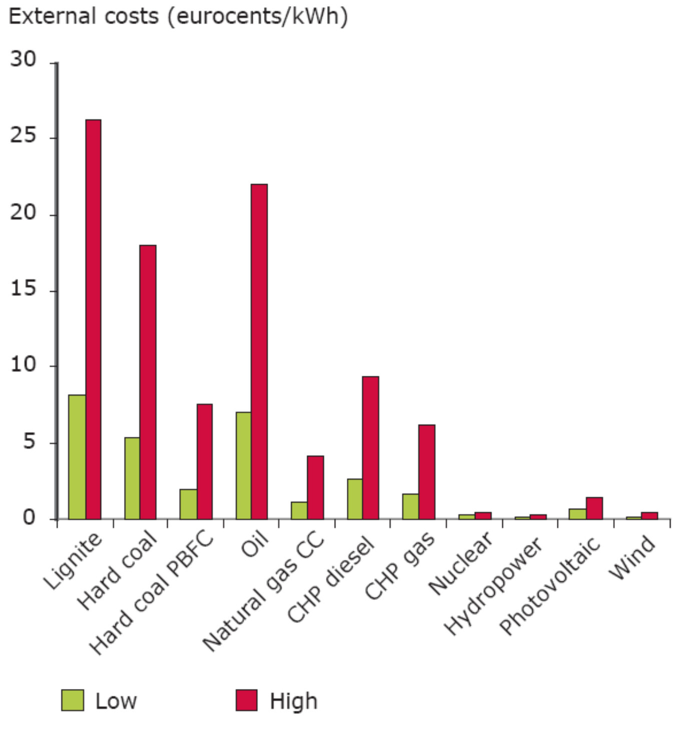
[1] GDP expressed in constant 2000 Euros

also costs associated with non-health impacts. SO_2 is the main pollutant of concern for building damage, though ozone does affect certain materials. The secondary pollutants formed from SO_2, NO_X and VOC also impact on crops and terrestrial and aquatic ecosystems.

Damages from climate change, associated with the high emissions of greenhouse gases from fossil fuel based power production, also have considerable costs. However, given the long-time scales involved, and the lack of consensus on future impacts of climate change itself, there is considerable uncertainty attached to these global warming values. The external costs of CO_2 emissions must thus be interpreted with care. The authors of a recent study on the impacts and costs of climate change (Watkiss et al., 2005) stress that there is no single value and that the range of uncertainty around any value depends on ethical as well as economic assumptions. The study concludes that 'lower indicative estimate for the marginal damage costs for the full risk matrix might result in a minimum value of 15 EUR/t CO_2, a central illustrative estimate of some 25 EUR/t CO_2, and an upper indicative estimate of at least 80 EUR/ t CO_2 and possibly much higher (for current, year 2000 emissions).' Values used in this factsheets are 19 EUR/t CO_2 (based on ExternE-Pol) and 80 EUR/t CO_2.

The overall level of these externalities will depend upon a number of factors including: the fuel mix for electricity generation (e.g. the use of coal releases far more CO_2 and air pollutants than gas); the efficiency of electricity production (as the higher this is the less input fuel, and hence output emissions, are required to produce each unit of electricity); the use of pollution abatement technology, and the location of the plant itself. Environmental and social externalities are highly site specific and so results will vary widely even within a given country according to the geographic location. Results from the CAFE (Clean Air for Europe Programme) have highlighted that the highest damages are found from emissions in the central parts of Europe and the lowest from countries around the borders of Europe. This reflects variation in exposure of people and crops to the pollutants of interest – emissions at the borders of Europe will affect fewer people than emissions at the centre of Europe, due to the degree of urbanisation and population density, and because the analysis did not account for non-European border countries.

Figure 2: Estimated average EU-25 external costs for electricity generation technologies in 2003



Data source: ExternE-Pol, 2005 ; CAFE, 2005 ; European Environment Agency/ETC

Note: Average emissions per unit of electricity generation are taken from ExternE-Pol (2005) and include emissions from the operation of the power plant and the rest of the energy chain. The components of external costs include the marginal damage cost factors for CO_2 (low estimate) and non-environmental social costs for non-fossil generating technologies (both taken from ExternE-Pol, 2005), and the high/low marginal damage cost factors for SO_2, NO_X, NMVOCs and PM2.5 (taken from CAFE). The high estimate for the external costs of CO_2 emissions is taken from Watkiss et al. (2005). For nuclear, only parts of externalities could be included. PBFC means pressurised fluidised bed combustion, CHP means combined heat and power, CC means combined cycle[2].

[2]Average emissions per KWh of electricity produced are not country specific. Country-specific data are 1) pollutant specific emissions from electricity production, 2) pollutant specific CAFE damage cost factors and 3) pollutant specific damage cost factors for CO_2 (baseline). For a given pollutant (e.g. SO_2) and country the total damage cost is calculated by multiplying the level of emissions and the (EUR per tonne of SO_2

Traditional fossil systems (coal, oil and to a lesser extent natural gas) exhibit the highest external costs for electricity generating technologies, in the range of 1.1 c EUR/kWh (for advanced gas technologies using the lower bound estimate of damage costs cEUR/kWh) to 26.3 cEUR/kWh (for traditional coal plants using the higher bound estimate of damage costs – 8.1 cEUR/kWh when using the lower bound). These fuels accounted for around 55 % of all electricity production in 2003 (see EN27 for more details). The majority of these external costs occur during the production of the electricity itself (i.e. from the burning of coal and release of specific pollutants to air, etc), although there is a small component associated with other parts of the fuel cycle (e.g. due to the mining and transport of the fuel). The introduction of advanced technologies (such as combined cycle (CC) and pressurised fluidised bed combustion (PFBC)) can substantially reduce the external costs of fossil systems, but they still remain in the range 1–8 c EUR/kWh. This also applies to cogeneration, for which gas technology generates external costs one third lower than diesel technology. Renewable energy and nuclear power show the lowest damages per unit of electricity. Nuclear external costs are in the range 0.2–0.4 cEUR/kW (of which around 70 % is due to radioactivity; but no major accidents assumed), with a similar cost associated with wind energy. Solar PV panels show a higher cost due to primarily to more energy intensive manufacturing requirements, in the range 0.7–1.4 cEUR/kW, although this is still considerably less than fossil generation.

The fall in external costs observed over the period 1990 to 2003 was primarily due to a combination of fuel switching away from coal to natural gas (and a smaller component from the increased use of renewable energy, which in general leads to far lower external costs than fossil fuels); the ongoing improvement in generation efficiency (in part due to the use of higher efficiency gas plant), and the use of pollution abatement technology, such as Flue Gas Desulphurisation in coal plants.

Significant falls in the external costs can be seen in most Member States; Slovakia, Czech Republic, Germany, the United Kingdom, Latvia, Denmark, and Lithuania all reduced their external costs per unit of electricity produced by more than 60 %. This was mainly as a result of the closure of old and inefficient coal-fired plants and their replacement with either newer, more efficient coal-fired plants or new gas-fired plants and the implementation of emission abatement measures (see EN08). In eastern Europe this was triggered primarily by economic restructuring and a decline in heavy industry (in Germany this occurred in the early part of the 1990s due to reunification) whereas in the United Kingdom it was due primarily to economic factors whereby gas became the fuel of choice for new plant, which also led to higher overall generating efficiencies from the use of combined cycle gas turbines (CCGT).

However, many of the new Member States still have some of the highest external costs on a per kWh basis. The externalities also vary between the older Member States, as a result both of the fuel mix and location; higher damages typically occur from emissions in countries in western Europe (e.g. Germany, the Netherlands, Belgium) because of the large population affected. Countries with lower mean externalities are Austria, Finland and Sweden, reflecting their low population density and greater use of nuclear and renewable energy and, in particular, hydropower. The low level of mean externalities found in France is explained by the intensive use of nuclear energy, with low release of air pollutants and CO_2.

At present, energy prices and taxation often do not reflect the full extent of external costs. However, progress is being made; with the absolute level of taxation increasing (see EN31 and EN32) and the introduction of the EU emissions trading scheme putting a price on carbon dioxide emissions. Full cost pricing (incorporating all environmental costs) is a long-term goal, but there are difficulties, notably the lack of consensus about the acceptability and validity of damage cost values. It should also be highlighted that taxes or other economic instruments are not the only way to internalise external costs; regulation are a way of internalising the costs as they may have a feedback on production costs.

emitted) damage cost factor (low or high). This is repeated for each country to obtain the, weighted, total EU damage cost of SO_2. This cost is then divided by the EU SO_2 emissions from electricity production to get an estimate, for the EU, of the implicit (€ per tonne of SO_2 emitted) damage cost factor. The latter is then multiplied by the fuel-specific EU SO_2 emissions per kWh to estimate the external costs (€ cents per kWh from e.g. lignite in terms of SO_2 emissions). Damage cost factors are not fuel specific but pollutant specific. The same SO_2 factor therefore applies to all fuels (lignite, hard coal etc). The external-costs estimate for a particular pollutant is different depending on the fuel because of different average emissions per kWh. The same process is repeated for the remaining pollutants and high/low damage factors. Finally, the external costs of each of the pollutants (for high and low separately) are added up according to individual fuels (as shown in the chart).

2. Indicator rationale

2.1 Environmental context

The external costs of the energy sector are those that energy producers and consumers impose on others without paying the consequences, including the impacts of air, waste and water pollution and of climate change. The social costs are higher than the private costs as these external costs are not included in the conventional market prices for electricity, which contributes to inefficiencies in resource allocation decisions. By including external costs in market prices, such inefficiencies can be corrected.

Externalities are most commonly incorporated through environmental taxes and charges or tradable permits (see EN34). Internalising all external costs (to get full cost pricing) would be difficult in the energy sector in Europe. However, it is still desirable to assess external costs to obtain cost ‘adders’, which although they may be different from the true external costs, are in line with environmental objectives set through political and societal consensus.

The most extensive study concerning externalities of the energy sector is the ExternE project and a number of subsequent studies, which provides a bottom up analysis of the external costs of the fuels used in the electricity supply sector. The ExternE methodology produces a damage value, expressed per kWh electricity or per tonne of pollutant. It focuses on the cost to human health, crops, materials, forests, ecosystems and climate change. It can include damages at all fuel cycle stages from fuel extraction to generation.

Following on from the original ExternE project, the methodology for calculating external costs has been further developed and improved in a number of projects including New-Ext (2004), ExternE-Pol (2005) and the cost-benefit analysis undertaken for the CAFE programme. The latter two were used to produce this fact sheet.

2.2 Policy context

The sixth environmental action programme stresses the need to internalise external environmental costs. It suggests a blend of instruments that include fiscal measures, such as environment-related taxes and incentives, and a phase-out of subsidies that counter the efficient and sustainable use of energy. The EU Sustainable Development Strategy, adopted by the European Council in Gothenburg in June 2001, aims to reconcile economic development, social cohesion and protection of the environment. A set of indicators including the external costs of energy use is being developed to monitor, assess and review the Strategy.

A particular policy is the Community Framework for Taxation of energy products and electricity (Directive 2003/96/EC replacing 92/81/EEC). Its aim is thus to improve the operation of the internal market by reducing distortions of competition between mineral oils and other energy products. In line with the Community's objectives and the Kyoto Protocol, it encourages more efficient use of energy so as to reduce dependence on imported energy products and limit greenhouse gas emissions. Also in the interests of protecting the environment, it authorises Member States to grant tax advantages to businesses that take specific measures to reduce their emissions.

As well as this, CO_2 emissions from combustion plants larger than 20MW emissions are covered by their participation within the EU emissions trading scheme (Directive 2003/87/EC). In addition to helping to internalise the external costs of climate change from power generation it will also help promote a shift to less carbon intensive fuels for electricity generation, such as gas, as well as improvements in efficiency.

Although not aimed primarily at internalising external costs, other EU policies have and will continue to help lower the overall external costs of electricity generation, in particular: the Large Combustion Plant Directive (2001/80/EC) which aims to control emissions of SOx, NOx and particulate matter from large (>50MW) combustion plants and hence favours the use of higher efficiency CCGT as opposed to coal plants, as well as the use of pollution abatement technology; and smaller plants covered under the IPPC Directive (96/61/EC) which also provides emissions limits for particular air pollutants, and emphasises the use of Best Available Technology Not Entailing Excessive Cost particularly in relation to pollution abatement technology.

References

CAFE, Clean Air for Europe Programme http://europa.eu.int/comm/environment/air/CAFE/.

Directive 96/61/EC concerning integrated pollution prevention and control.

Directive 2001/80/EC on the limitation of emissions of certain pollutants into the air from large combustion plants.

Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC.

Directive 2003/96/EC restructuring the Community framework for the taxation of energy products and electricity.

ExternE – Externalities of Energy http://www.externe.info/.

ExternE-Pol (2005) Externalities of Energy: Extension of accounting framework and policy applications, Report to the European Commission DG Research, Technological Development and Demonstration (Contract No: ENG1-CT2002-00609), produced by ARMINES/Ecole des Mines de Paris, et al.

New-Ext (2004) New Elements for the Assessment of External Costs from Energy Technologies, Report to the European Commission DG Research, Technological Development and Demonstration (Contract No: ENG1-CT2000-00129), produced by IER (Institute for Energy Economics and the Rational Use of Energy) et al.

Watkiss, P.; Downing, T.; Handley, C.; Butterfield, R. (2005). The Impacts and Costs of Climate Change. Final Report to DG Environment. September 2005. Published at http://europa.eu.int/comm/environment/climat/studies.htm.

Meta data

Technical information

1. Data source (incl. data of most recent update)
   Historical emissions - European Environment Agency - European Topic Centre on Air and Climate change.
   Historical electricity data - Eurostat http://europa.eu.int/comm/eurostat/
   Marginal Damage cost factors for air pollutants (SO_2, NO_x, NMVOCs, NH_3, PM2.5) – CAFE (Clean Air for Europe) programme http://europa.eu.int/comm/environment/air/CAFE/
   Marginal damage cost factors for CO_2 and other non-environmental social costs from nuclear and non-thermal renewables: ExternE-Pol (2005)
   Marginal damage costs for CO_2 high estimate are taken from (Watkiss et al., 2005)

2. Description of data / Indicator definition
   The indicator provides an estimate of the external costs (due to greenhouse gas emissions, other air pollutants and other non-environmental social costs) from each unit of electricity generated within each Member State. Marginal damage costs per unit of pollutant emitted (or per unit of electricity generated by fuel-type in the case of the non-environmental social costs) are multiplied by the overall level of emissions (from common reporting format category 1A1a Public electricity and heat production) in 1990 and 2003 in each Member State to produce an overall cost for that year. Added to this is the overall cost from non-environmental social factors for nuclear and non-thermal renewable plants, based upon the per kWh marginal damage factors and electricity production from each of these sources in each Member State. The overall damage cost is then divided by the total electricity production in that year to produce an external cost in eurocents/kWh.

3. Geographical coverage: EU-25 excluding Cyprus, Malta and Luxembourg

4. Temporal coverage: 1990 and 2003.

5. Methodology and frequency of data collection:
   CO_2 emissions data are annual official data submission to UNFCCC and EU Monitoring mechanism. Combination of emission estimates based on volume of activities and emission factors. Recommended methodologies for emission data collection are compiled in the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 1997), supplemented by the 'Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories' (IPCC, 2000) and UNFCCC Guidelines (UNFCCC, 2000).
   SO_2 and NOx emissions data are annual country data submissions to UNECE/CLRTAP/EMEP. Combination of emission measurements and emission estimates based on volume of activities and emission factors. Recommended methodologies for emission data collection are compiled in the Joint EMEP/CORINAIR Atmospheric Emission Inventory Guidebook 3rd edition EEA Copenhagen EEA (2001).
   Energy data collected annually by Eurostat. Eurostat definitions for energy statistics http://forum.europa.eu.int/irc/dsis/coded/info/data/coded/en/Theme9.htm
   Eurostat metadata for energy statistics: http://europa.eu.int/estatref/info/sdds/en/sirene/energy_base.htm

6. Methodology of data manipulation:
   The three components of the external cost shown in the indicator are:
   a) Air pollution costs for (SO_2, NO_x, NMVOCs, NH_3, PM_{10}) in each Member State calculated from: High/Low marginal damage costs (in EUR/tonne of emission) taken from CAFE multiplied by relevant emissions data from category 1A1a Public electricity and heat production. This produces a separate high and low cost for these components. CAFE only contains a value for marginal damage cost for PM2.5 rather than PM_{10}, but the set of emissions data is poor for PM2.5 compared to PM_{10}. Hence a value of Marginal damage cost for PM2.5 * 0.6 = Marginal damage cost for PM_{10} is used.

b) CO_2 costs in each Member State calculated from: Marginal damage cost (in €/tonne emission) taken from ExternE-Pol (2005) and Watkiss et al. (2005) multiplied by relevant emissions data from 1A1a Public electricity and heat production.
c) The non-environmental social costs for nuclear and non-thermal renewables (Hydro, Solar PV, Geothermal, Wind) in each Member State are calculated from: The marginal damage cost (in eurocent/kWh of electricity produced by the technology) multiplied by the overall level of electricity production from each technology - corresponding to Eurostat codes: 107005 gross electricity generation wind turbines; 107023 gross production from photovoltaic systems; 107001 Gross electricity generation - Hydro power plants; 107002 gross electricity generation - Geothermal power plants.
The 3 components are summed to produce an overall damage cost for each Member State. These are then divided by 107000 total gross electricity generation to produce an external cost in eurocents/kWh. Components b) and c) are constant and these are added to the high and low components from a) to produce an overall high estimate and an overall low estimate for each Member State.

Qualitative information

7. Strengths and weaknesses (at data level)
A complete data set for all emission types in the 1A1a Public electricity and heat production category is not available for Malta and Luxembourg and so has been excluded. Cyprus has also been omitted due to the CAFE conclusion that marginal damage cost factors as a result of modelling work, for this country, were not considered sufficiently robust for inclusion in the final report. Also, as mentioned in section 6) above, the availability of PM2.5 emissions data under category 1A1a was poor compared to PM_{10}, so the PM_{10} emissions were applied to a modified PM2.5 marginal damage cost factor from CAFE.
Energy data have been traditionally compiled by Eurostat through the annual Joint Questionnaires, shared by Eurostat and the International Energy Agency, following a well established and harmonised methodology. Methodological information on the annual Joint Questionnaires and data compilation can be found in Eurostat's web page for metadata on energy statistics.
http://europa.eu.int/estatref/info/sdds/en/sirene/energy_sm1.htm
Emissions: Officially reported data following agreed procedures. E.g. CO_2 data are based upon annual submissions under the UNFCCC, and SO_2 and NO_x emissions data are annual submissions to UNECE/CLRTAP/EMEP
For some of the emissions data the ETC-ACC gap-filling methodology has been used. Where countries have not reported data for one, or several years, data for emissions from public conventional thermal power production has been calculated as a proportion of the emissions from all energy industries (which includes emissions from refineries etc) by applying a scaling factor. This scaling factor has been calculated as the ratio of emissions from public conventional thermal power production to emissions from all energy industries for a year in which both data sets exist (usually 2002). It is recognised that the use of gap-filling can potentially lead to inaccurate trends, but it is considered unavoidable if a comprehensive and comparable set of emissions data for European countries is required for policy analysis purposes.

8. Reliability, accuracy, robustness, uncertainty (at data level):

CO_2 emission estimates:
The IPCC believes that the uncertainty in CO_2 emission estimates from fuel use in Europe is likely to be less than ± 5 %. In 2005 for the first time uncertainty estimates were calculated for the EU-15 in EEA (2005a). For energy related greenhouse gas emissions the results suggest uncertainties between +/– 1 % (stationary combustion) and +/– 11 % (fugitive emissions). The uncertainty associated with CO_2 emissions from public heat and electricity production (IPCC sector 1A1a) has been estimated at around 3 % in 2003. For the new Member States and some other EEA countries, uncertainties are assumed to be higher than for the EU-15 Member States because of data gaps.
The external costs of CO_2 emissions are taken from ExternE-Pol and Watkiss et al. (2005). They must thus be interpreted with care, due to uncertainties based on the long-time scales involved, and the lack of consensus on future impacts of climate change itself. Watkiss et al. (2005) stress that there is no single value and that the range of uncertainty around any value depends on ethical as well as economic assumptions. The study concludes that 'a lower indicative estimate for the marginal damage costs for the full risk matrix might result in a minimum value of 15 EUR/tCO_2, a central illustrative estimate of some 25 EUR/tCO_2, and an upper indicative estimate of at least 80EUR/ tCO_2 and possibly much higher (for current, year 2000 emissions).' Values used in this factsheets are 19EUR/t CO_2 (based on ExternE-Pol) and 80 EUR/ t CO_2.

SO_2 emission estimates:
Sulphur dioxide emission estimates in Europe are thought to have an uncertainty of about ±10 % as the sulphur emitted comes from the fuel burnt and therefore can be accurately estimated. However, because of the need for interpolation to account for missing data the complete dataset used here will have higher uncertainty. EMEP has compared modelled and measured concentrations throughout Europe (EMEP 1998). From these studies differences in the modelled annual averages (for a specific point in time) have been estimated in the order of ± 30 % consistent with an inventory uncertainty of ±10 % (there are also uncertainties in the measurements and especially the modelling).

NOx emission estimates:
NOx emission estimates in Europe are thought to have an uncertainty of about ±30 %, as the NOx emitted comes both from the fuel burnt and the combustion air and so cannot be estimated accurately from fuel nitrogen alone. EMEP has compared modelled and measured concentrations throughout Europe (EMEP 1998). From these studies differences for individual monitoring stations of up to a

factor of two have been found. This is consistent with an inventory of national annual emissions having an uncertainty of ±30 % (there are also uncertainties in the measurements and especially the modelling).
For all emissions the trend is likely to be much more accurate than individual absolute annual values - the annual values are not independent of each other. However not all countries apply changes to methodologies back to 1990.

There are then three further principle issues in calculating external costs from a given level of pollution. The first is in modelling the dispersion of pollutants from a source across a region or potentially Europe as a whole to examine where the damage from these pollutants is likely to occur. The second step is examining dose (or concentration) response relationships to estimate how much damage a pollutant is likely to cause at a particular point, for example, the impact on health will be higher in areas where the population is more 'vulnerable' (i.e. a higher proportion of children and the elderly). The third issue is how the level of damage that is caused is valued in monetary terms. In certain cases this is 'relatively' straightforward, for example, when air pollution affects crop yields market values for the loss of the particular crops can be used. Far more contentious is the impact on health, particularly in relation to the impact of long-term exposure to air pollution and mortality (so called chronic mortality) as there are varying methods such as VOLY (Value of Life Years which estimates the economic loss in terms of healthy Years of Life Lost or YOLL from the impact of the pollution), or the use of VSL (the Value of a Statistical Life as a whole which generally leads to much higher valuations of external costs). However, considerable uncertainties have been acknowledged regarding many aspects of the methodology that have been applied in the ExternE and follow-on projects, which have been used to help quantify and monetise the scale of these external costs. Research is continuing to reduce the uncertainties present in this type of analysis.
There are considerable uncertainties in these latter steps (following the estimate of emissions/pollutants and modelling of their dispersion across the EU) of the methodology to estimate overall external costs. In particular:

- estimating the level of damage caused by a particular pollutant (the dose/concentration response relationship),
- valuing the impact of this damage in monetary terms.

This is particularly difficult in the case of health impacts whose results are due primarily to the size of the air pollution externality, which is determined by two main elements (directly based on the above 2 steps), both of which are related to the impact of long-term exposure to air pollution and mortality (so called chronic mortality):

- The quantification method used for air pollution and long-term mortality (i.e. the dose-response relationship),
- The valuation estimates used to value these changes in long-term mortality.

Chronic effects on mortality have become the main focus for quantification of the health impacts of particulate exposure. The analysis uses the risk estimates that are based on analyses of the American Cancer Society (ACS) cohort by Pope et al (1995,) and updated in 2002. The main results from the Pope et al (1995) study give a lower bound estimate of increase in death rates of 3 % per 10 μgm-3 PM2.5, a central estimate of 6 % per 10 μgm-3 PM2.5,and an upper bound estimate of 9 % per 10 μgm-3 PM2.5. ExternE-Pol (2005) uses a lower bound rate (2 or 3 % per 10 μgm-3 PM2.5). However, CAFE, following advice and guidance from WHO, uses the central estimate of 6 % per 10 μgm-3 PM2.5. Therefore the basis upon which the damage caused by the pollutants is assessed (the step before this damage is then valued) is different and CAFE will hence produce generally higher numbers than ExternE-Pol. There is also one additional difference in that CAFE assumes that all components of PM2.5 are equally hazardous. ExternE-Pol assumes that nitrates have a lower hazard to health, and uses an adjusted (and hence lower) risk rate for the nitrates.
In terms of the physical impacts quantified, the guidance from the WHO (World Health Organisation) expresses chronic mortality effects principally in terms of change in longevity. This also leads to estimates of the change in longevity aggregated across the population (otherwise referred to as 'years of life lost' or YOLL) as the most relevant metric for quantification and valuation. Both ExternE-Pol and CAFE use this metric. They also use the same estimates from NewExt (2004), in terms of the VOLY (Value of Life Years), to value these changes. However, CAFE, following advice from the peer review, also works in terms of attributable deaths from chronic mortality. The peer review of the CBA (Cost Benefit Analysis) methodology pointed out that direct, credible estimates of the VOLY are lacking, that the estimates to be used in CAFE are derived computationally and that to be applied correctly, VOLYs should be age specific. To address this, CAFE also quantified premature mortality benefits based on the cohort studies in terms of 'attributable deaths' and valued these using a Value for a Statistical Life or VSL approach (also derived from the NewExt project). This leads to a higher estimate of damage costs compared to the VOLY approach, and hence a range of values for the damage costs. NewExt provided both mean and median estimates for VOLY and VSL. ExternE-Pol used the median estimates for VOLY only. However CAFÉ based upon the above peer review advice uses both mean and median estimates for VOLY and VSL (see below). The use of both the VOLY and VSL approaches, with mean and median estimates, leads to four estimates in CAFE (VOLY median, VSL median, VOLY mean, VSL mean).

	VSL	VOLY	Derived from:
Median (NewExt)	EUR 980 000	EUR 52 000	Median value 5:1000
Mean (NewExt)	EUR 2 000 000	EUR 120 000	Mean value 5:1000

CAFE itself does not make any recommendation on which of the four estimates to use – they are all provided as four equally valid results. However, in the case of externality analysis, it is generally recommended to use the full range of low and high estimates. Hence the indicator with the high estimate is based upon CAFE's use of the Mean VSL in the assessment of the marginal damage cost factors for the air pollutants (NO_x, SO_2, NMVOCs, PM_{10}, NH_3) and the Median VOLY in the case of the low estimate.

9. Overall scoring – historical data (1 = no major problems, 3 = major reservations):
   Relevance: 1
   Accuracy: 2.5
   Comparability over time: 2
   Comparability over space: 2